Bayhealth Medical Center

Dover, Delaware

Final Report

The Pennsylvania State University

AE Faculty Advisor:Chimay Anumba

Architectural engineering senior thesis

4/7/2011

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Construction Management

Bayhealth Medical Center Expansion Phase 2

640 S State St. Dover, DE

Christopher Barron

Construction Management

Project Overview

Owner: Bayhealth Medical Center inc

Architect: Becker Morgan Group inc.

Engineer: EwingCole

GC: Whiting-Turner

Total Height: Varies 2-4 floors (68 ft total)

Building Area: 226,271 sq ft

Contract Type/Cost: GMP 65 million

Construction Dates: Jan 2009—Nov 2011

Mech/Electrical

⇒ Mechanical

4 VAV units (48,000-17,500 CFM)

3 CV-VFD (135,00-2,875 CFM)

5 water tube boilers with 10,050 MBH output

3 centrifugal water-cooled chillers with 1450 ton capacity

⇒ Electrical

2 sets of main service switch gear with 2500/3325 KVA, 3Ø,60Hz

Emergency system with 2 3125 KVA, 3Ø,60Hz

generators

Architectural Features

⇒ Room types

emergency department, oncology (both chemo and radiation), heliport, security, pharmacy, diagnostic imaging, and shell space.

⇒ Building Façade

mix of red brick, metal panels, and glass curtain wall system. The Pavilion's architecture matches the brick-work and glass curtain walls of the existing structure, but employs more glass and metal panels, giving it a more modern look.

Structural System

⇒ Foundation

5" reinforced SOG that is tied into grade beams along the exterior, and 114 16" diameter reinforced auger cast piles that are embedded 20'-30' into the ground.

⇒ Framing

50 ksi steel braced column and frame system

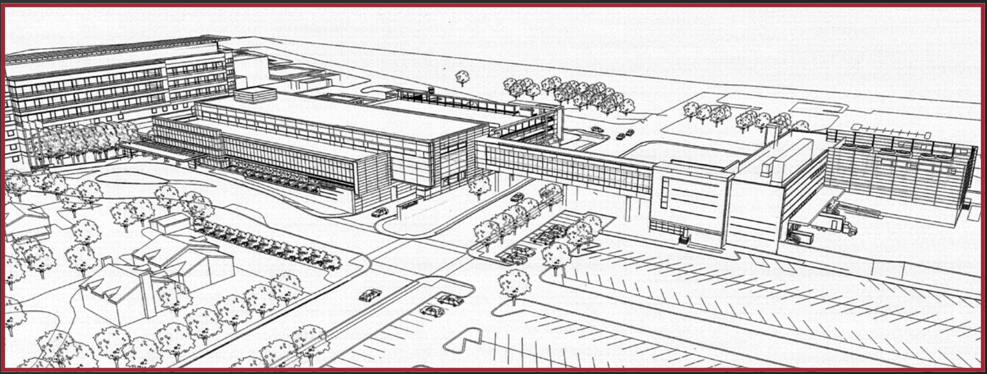
⇒ Floor System

4.5" thick normal weight concrete on 20 gauge composite decking

3.25" thick light weight concrete on 18 gauge composite decking

⇒ Roof

4.5" thick normal weight concrete on a 18 gauge composite metal decking. Roof build up is comprised of tapered 3" rigid insulation covered with a single ply EPDM membrane.



EwingCole Architects Engineers Interior Designers Planners

WHITING-TURNER

BECKER MORGAN GROUP

PENNSTATE 1855

http://www.engr.psu.edu/ae/thesis/portfolios/2011/crb5084/index.html

II. Executive Summary

This senior thesis final report is intended to provide an in depth analysis of the bayhealth medical center located in Dover, Delaware. This report contains information regarding owner information, bayhealth 10 year strategic planning, an in depth summary of the current phase two expansion, summary of the podium building and its systems, project team, companies involved, a summary of construction costs, and a summary of the podium building's schedule. This senior thesis final report also contains an in depth look into four analysis topics. The analysis topics that are discussed in this report are a look into issues encountered with the curtain wall system, a green roof addition, a look into prefabrication, and 3-D coordination. Also Two breadth topics, a structural and a mechanical, that both involved the green roof analysis will be discussed.

Analysis One:

The bayhealth medical center expansion's façade is comprised of three different systems: metal panels, masonry brick, and a curtain wall system. The problem that the project team ran into was tying the Eastern curtain wall facades waterproofing into the other two systems efficiently and effectively.

Analysis Two:

There were very few sustainable ideas implemented on the bayhealth medical center expansion. Green roof technology is beginning to emerge in the construction industry today as a way to not only make a building more environmentally friendly, but also as a way to provide savings to the owner in the long run. A green roof system is a great way to reduce storm water runoff, reduce the buildings heat island effect, and also reduce mechanical loads.

Analysis Three:

Because of the extensive amount of MEP systems needed in a hospital, a lot of time and money is spent installing these systems. Since these systems are so important to the overall building, their installation is usually on the schedules critical path. Because cost and quality are paramount to the bayhealth medical center expansion owner, the installation of these systems must be watched over diligently. The installation of these systems is not only time consuming and expensive, but can also be very problematic.

Analysis Four:

BIM seems to be one of the most talked about topics in the construction industry today. It is completely revolutionizing how construction projects are being done today. Using even the basic concepts of BIM, like clash detection and 3D coordination, can greatly reduce the time and money it takes to ensure that building systems can be properly installed, and reduce the number of change orders and field problems that occur due to improper coordination.

III. Acknowledgments

Academic Acknowledgements:

Penn State AE Faculty

Dr. Anumba (CM Advisor)

Industry Acknowledgements:

WT
WHITING-TURNER

GREENGRID
The Natural Choice for Your Roof

EwingCole
Architects
Engineers
Interior Designers
Planners

SKANSKA

Bayhealth
Medical Center

Special Thanks To:

The Bayhealth Medical Center Project team

Mr. Craig Dubler

My AE Friends

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V. Project Overview

A. Introduction

In 1927 Kent general hospital was opened because of a large need for healthcare in the Dover Delaware area. Since then, the bayhealth medical center has become central and southern Delaware's largest healthcare system provider with a medical staff of 2,900 and 458 physicians. It is comprised of Kent General, Milford Memorial Hospital, Middletown Medical Center, and numerous satellite facilities throughout the area. bayhealth's mission is to improve the health status of all members of the bayhealth community, and to distinguish themselves as a health care provider of choice by delivering the highest quality of health care while also giving exceptional patient experiences. Over the past few years bayhealth has received numerous awards such as

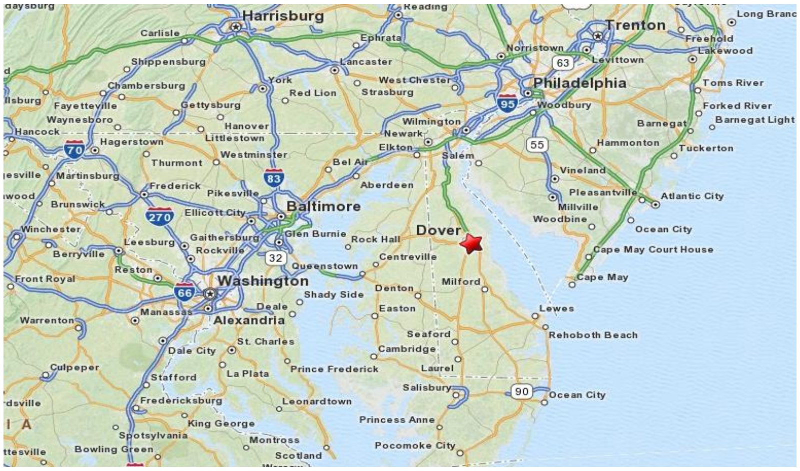


Figure 1: The project is located 90 miles east of Washington DC near route one in Dover

- Ranked Best (#1) in Delaware for Overall Critical Care (2010)
- Clinical Excellence Award for Overall Critical Care (2009 & 2010)
- Recognized by J.D. Power and Associates for providing an "Outstanding Inpatient Experience" (2007 – 2009)

There are a total of three phases planned in the bayhealth medical centers ten year strategic plan that is designed to address their present and future healthcare needs. The first phase consisted of three new floors on top of the existing building which consisted of private rooms. The phase one expansion also included the center for women and infants on the fifth and sixth floor and also a medical surgical unit on the fourth floor. The phase two expansion consists of several new buildings and departments. The pavilion building connects the existing hospital to a new patient parking garage and also to a bridge that leads to the new central service building. The bridge also offers an enclosed pathway for bayhealth employees to walk from the employer parking lots into the hospital. The phase two expansion will also include a new helipad, and shell space located on the third floor of the podium building for a planned phase three expansion. In addition the phase two expansion will include miscellaneous site work improvements such as paving, sidewalks, patios, landscaping, irrigation systems, signage, and lighting. The phase three expansion will be an addition of 8 stories to the pavilion build that will house even more patient rooms. A breakdown of the phase two expansion is summarized in the chart below:

buildings/department	sq ft	cost	details
pavilion building	215,000	65 million	will house 225 patient beds
welcome center	15,000		includes a retail center
central service building	35,000	25 million	Will house a material handling facility which includes new boilers, chillers, and and also a new power plant emergency electric generators
emergency department	35,000		Will provide the space to expand to up to 56 treatment bays.
integrated cancer center	35,000		Will house both radiation on the first floor and medical onocology services on the second floor.
Bridge	6,500	three million	connecting the central service building and employee parking lots to the pavilion
parking garage	135,000	ten million	375 available parking spaces

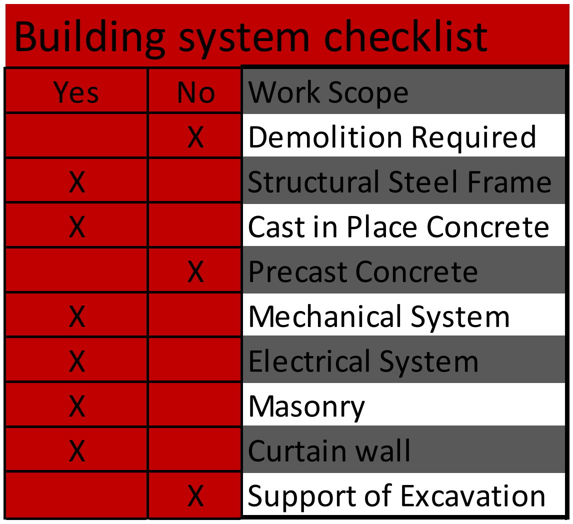
B. Pavilion Building

Figure 2 courtesy of the Bayhealth medical center

The pavilion building is the focus of this senior thesis since it is the largest part of the phase two expansion. It is 215,000 SQ feet and will house a 225 bed patient care tower, an emergency department, oncology (both chemo and radiation), heliport, security, pharmacy, Diagnostic imaging, and shell space. The projected cost of construction to the pavilion building is a GMP contract of 65 million. A more complete breakdown of the pavilions cost will be discussed in a later section. Construction was started on December 24, 2007 and is expected to be completed in May 2012. Whiting-Turner was chosen as the General contractor to complete the entire phase 2 expansion due to their expertise in construction of the healthcare field. There are current plans of a future addition in ten years of eight additional floors to the pavilion building, which will house further patient beds. The owner has three overall expectations for this project. First, the owner expects to job to be done on schedule. Because of the level of complexity of the project, the owner also expects a high level of quality on this project. Finally, since bayhealth is a not for profit organization, the project needs to come in under budget.

C. Building System Summary

The podium buildings systems are shown in the chart below and are summarized by scope.



Building system checklist

Yes	No	Work Scope
	X	Demolition Required
X		Structural Steel Frame
X		Cast in Place Concrete
	X	Precast Concrete
X		Mechanical System
X		Electrical System
X		Masonry
X		Curtain wall
	X	Support of Excavation

`Structural Steel Frame

The steel structure is a four story braced frame system with an average bay size of 30’X30’. Column sizes range from one floor W10X33 to the oversized W14X159. Some of the structural system is oversized, because of future plans to add additional stories to the pavilion. The floor system used in the pavilion is a 3.25” thick light weight concrete on 18 gauge composite decking reinforced with 6’X6’ pieces of W2.9XW2.9 welded wire fabric.

Cast in Place Concrete

All cast in place concrete is located in the basement and foundation of the pavilion. The foundation, walls, and slab on grade concrete must have a minimum of 3000 psi compressive strength at 28 days. The pile caps that range from 9 sq ft in size and 3.5’ thick to 286 sq ft in size and 6’ thick require 5,000 psi compressive strength at 28 days.

Mechanical System

Most of the pavilion’s mechanical systems are located in the central service building. It houses five 10,050 MBH water tube boilers, three 1450 ton capacity centrifugal water-cooled chillers, and three 4,500 GRM crossflow/induced draft cooling towers. The chilled water supply and return lines along with the high pressure steam lines are run underground from the central service building to two mechanical rooms located in the basement of the pavilion. The buildings five VAV AHU systems, which vary from 17,500 to 48,000 CFM, are also located in the basement of the pavilion. The Pavilion is completely sprinkled with a wet-pipe system.

Electrical System

There are two separate sets of switch gear located in the basement of the pavilion. Each set is able to handle 2500/3325 KVA, 3-phase, at 60 hertz. There is also two emergency generators located in the central service building able to handle 3125 KVA, 3-phase, at 60 hertz.

Masonry

All the masonry on this project is for architectural purposes only. A typical masonry wall assembly consists of 3 5/8" thick brick, a 3/8" air space, and a 2" exterior polystyrene insulation.

Curtain Wall

A curtain is used along the east and west sides of the pavilion. The majority of the glass curtain wall is along the east side, which is also the side of the main entrance.

D. Project Staffing Plan & Project Team

Staffing Plan	
Construction Manager	Peter Kelsey
Superintendent	Sam Nicolosi
Project Manager	Paul Horning
Project Manager	Joshua George
Project Manager	Dan Handley
Project engineer	Jaff Chapin
Project Engineer/QC	Chris Issa
Assistant PM/Scheduler	Todd Huber
Project Accountant/SEC	Kim Stevenson

Project Team	
Owner	Bayhealth Medical Center
CM Agency	Whiting-Yurner
Architect & Engineer	Ewing Cole
Structural Sub	Cives Steel Company
Roofing Sub	Tri-Sate Roofers
Fireproofing Sub	Cassidy Painting
Curtain Wall Sub	R.A. Kebbedy & Sons Inc
HVAC Sub	Delcard Associates
Electrical Sub	Nickle
T	
CIP Concrete Sub	DGS Concrete Construction Inc
Masonary Sub	Enertprise Masonary Corporation

E. Project Cost

The actual construction costs Summarized below are based on the GMP tabulation provided by Whiting-Turner Construction.

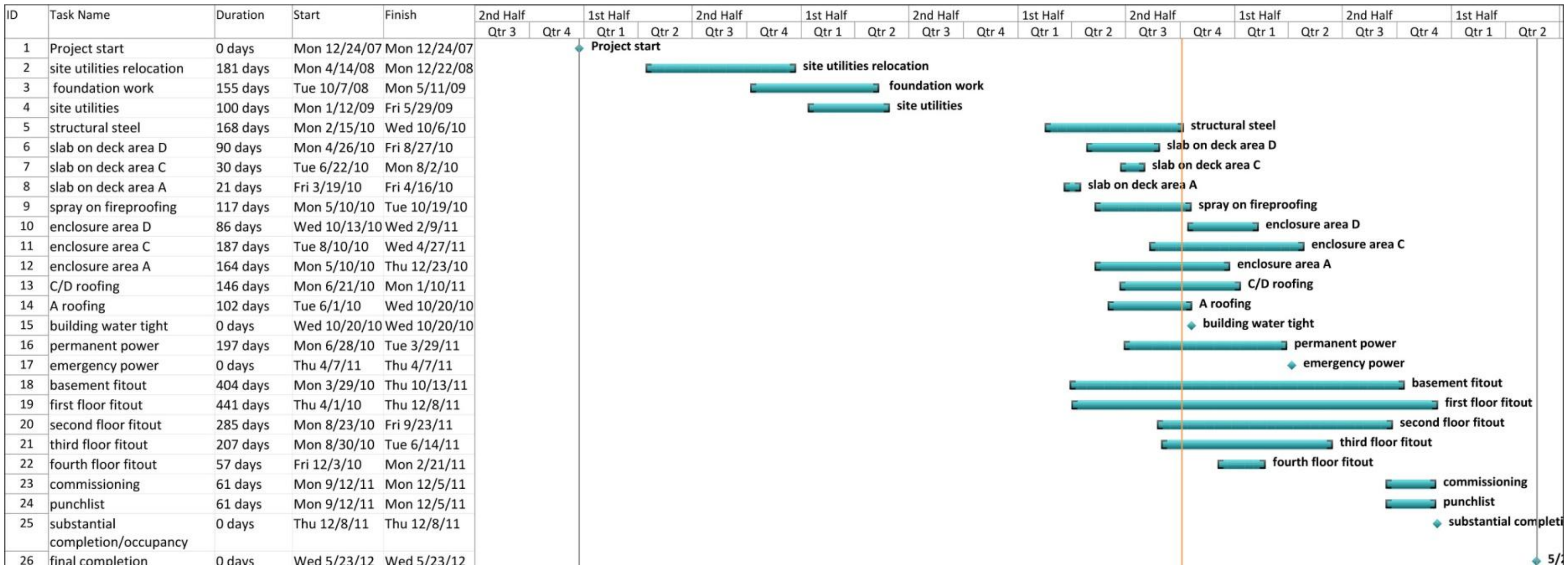
Actual Costs

Building Construction Cost	**$46,462,094.00**
CC/ SQ FT	**$216.10**
Total Project Cost	**$59,840,038**
Building Equip. Cost	**$13,491,368.00**
TC/ SQ FT	**$278.33**

Major Building Systems	**Actual**	**Per SF**
Concrete	$5,256,253.00	$24.45
Masonry	$1,519,209.00	$7.07
Structural Steel	$7,148,723.00	$33.25
Mechanical, Plumbing & HVAC	$9,052,082.00	$42.10
Electrical	$1,860,770.00	$8.65
Site Work	$4,165,925.00	$19.38

VI. Project Schedule Summary

The following schedule is a summary schedule based of a detailed 43 page schedule of the podium building. This schedule summarizes the construction of the pavilion building which will be from its start on November 7, 2008 to its estimated completion May 23 2012.



ID	Task Name	Duration	Start	Finish
1	Project start	0 days	Mon 12/24/07	Mon 12/24/07
2	site utilities relocation	181 days	Mon 4/14/08	Mon 12/22/08
3	foundation work	155 days	Tue 10/7/08	Mon 5/11/09
4	site utilities	100 days	Mon 1/12/09	Fri 5/29/09
5	structural steel	168 days	Mon 2/15/10	Wed 10/6/10
6	slab on deck area D	90 days	Mon 4/26/10	Fri 8/27/10
7	slab on deck area C	30 days	Tue 6/22/10	Mon 8/2/10
8	slab on deck area A	21 days	Fri 3/19/10	Fri 4/16/10
9	spray on fireproofing	117 days	Mon 5/10/10	Tue 10/19/10
10	enclosure area D	86 days	Wed 10/13/10	Wed 2/9/11
11	enclosure area C	187 days	Tue 8/10/10	Wed 4/27/11
12	enclosure area A	164 days	Mon 5/10/10	Thu 12/23/10
13	C/D roofing	146 days	Mon 6/21/10	Mon 1/10/11
14	A roofing	102 days	Tue 6/1/10	Wed 10/20/10
15	building water tight	0 days	Wed 10/20/10	Wed 10/20/10
16	permanent power	197 days	Mon 6/28/10	Tue 3/29/11
17	emergency power	0 days	Thu 4/7/11	Thu 4/7/11
18	basement fitout	404 days	Mon 3/29/10	Thu 10/13/11
19	first floor fitout	441 days	Thu 4/1/10	Thu 12/8/11
20	second floor fitout	285 days	Mon 8/23/10	Fri 9/23/11
21	third floor fitout	207 days	Mon 8/30/10	Tue 6/14/11
22	fourth floor fitout	57 days	Fri 12/3/10	Mon 2/21/11
23	commissioning	61 days	Mon 9/12/11	Mon 12/5/11
24	punchlist	61 days	Mon 9/12/11	Mon 12/5/11
25	substantial completion/occupancy	0 days	Thu 12/8/11	Thu 12/8/11
26	final completion	0 days	Wed 5/23/12	Wed 5/23/12

VII. Analysis of Issues Encountered With the Curtain Wall System

A. Problem Identification

The bayhealth medical center expansion's façade is comprised of three different systems: metal panels, masonry brick, and a curtain wall system. The problem that the project team ran into was tying the Eastern curtain wall facades waterproofing into the other two systems efficiently.

B. Research Goals

The goal for this analysis will be to study the current façade system used and investigate the reason or reasons making it water tight became so problematic. Then, after all these issues have been determined, a timeline will be constructed to portray the events that led up to and eventually caused the problem. These events will be summarized and several workable solutions will be presented.

C. Methodology

- Analysis of current façade systems
- Contact manufacturers for design consultation of current system
- Interview project team to discover exact problem(s) encountered
- Interview the bayhealth medical center owner to determine exact sequence of events
- Interview design team to determine exact sequence of events
- Construct timeline to portray events that caused the problem
- Summarize these events and provided other scenarios that would have avoided problem

D. Existing Curtain Wall System

The Curtain wall system that was used on the Bayhealth medical center expansion was the Schuco FW 60 mullion-transom system. This system is located on the eastern side of the podium building and vertically spans all three floors.

Figure 3: FW 60 mullion-transom system

The Schuco system was chosen by the architect for its flush appearance. This flush appearance of the structural glazing is achieved by using profiles that are only visible from the interior side. From the outside, only the glass and the shadow joints are visible. Also, because it is a gasket system it has a much smoother look, instead of having numerous caulked joints. Other features and benefits of the Schuco system include:

- Can support glass weights up to 990 lbs
- 2-part stainless steel spacers for a gas-tight edge seal
- Extended combination options for glazing thickness of internal and external panes
- New generation of fittings for vent weights up to 550 lbs with opening units

E. Testing Criteria

When a curtain wall system was selected for the bayhealth medical center, there were certain performance criteria that were established. These criteria were based off of one of the following codes depending on which of the following was the most stringent:

- International energy code
- Current ASRAE 90.1
- AAMA 101-93

The test chosen for measuring water penetration is the ASTM E 331that states for a minimum of 15 minutes at 15 psi with 5 gal/hr/sq ft there must be no water penetration. The testing was determined to occur over a typical three unit group including corner and special connection conditions. The height of the unit being tested was to be one full story and include both floor lines.

F. Water Proofing System

There were two waterproofing systems that were used while installing the curtain wall. The first was an air infiltration barrier (AIB) and a fluid-applied membrane air and vapor barrier (AVB). The product requirements for both the AIB and AVB waterproofing systems are listed in appendix B and C. The AVB and AIB systems are a spray on vapor/ air barrier that was installed in the following steps

1. Dispensed through spray equipment approved by the manufacturer
2. Spray on walls working from the bottom upward with overlapping passes
3. A minimum thickness when wet must be applied
4. Apply full thickness in one continuous coat

G. Problem Encountered with Curtain Wall System

The problem with the Curtain wall was first discovered during the first round of shop drawings and they became physically visible on the mock-up. When they actually saw how the metal panel and window system interacted, and how the AIB/AVB would have to tie into them they realized there would be problems. The project team ran into three main issues with tying the curtain walls waterproofing system into the other two building facade systems. The first was space constraints between the brick and strip windows if they would have tied the masonry into the window system, the brick would have needed to be installed first. In order to do that they would have had to leave a piece of the waterproofing material hanging out behind the brick in the cavity and then once the window was installed try to apply that material directly onto the window mullion. All this would have had to be done in a 5/8" caulking joint .This was impossible for them to do with such a tight area to work in. Another issue with the curtain wall into brick waterproofing was with the Schedule. Installing the brick is a dirty job and not delicate work like installing the glass into the curtain wall. Also, they would have ran into the issue of cleaning the brick, which is typically done with spraying acid onto the brick, would have had to been done. This would have caused possible damage to the window mullions if sequenced this way. The second issue they encountered was a constructability and sequencing issue. In order to adequately tie the Schuco curtain wall systems water proofing into the metal

Figure 4: Curtain wall mock up

panels waterproofing system the Curtain wall would have to of been installed before the metal panels. The metal panel to curtain wall assembly was supposed to go in a specific order

1. Back up wall (studs/sheathing)
2. window system framing
    a. this needed to be installed so the waterproofing material could then be tied between the sheathing and window system
3. Metal panels themselves
    a. attachment point was actually behind the glass
4. Install glass
5. Final trim piece

But if they would have installed the entire curtain wall system first, they would not have been able to install the metal panels the way that it was designed to be. The third problem encountered was an overall lack of design. The project was only about 70% designed when Whiting-Turner initially bid the project. This lack of accurate drawings made it impossible for Whiting-Turner to accurately determine how the Schuco system would be installed. The Owner also hired a skin consultant that had their own ideas of how the curtain wall should have been designed. But, they were not part of the project team until after Whiting-Turner bid the project, which was too late to help.

H. Schedule Implications of Waterproofing issue

Because getting the building enclosure watertight is along the projects critical path, the waterproofing issue encountered with the Schuco curtain wall system had a negative impact on the overall project schedule. A total of 18 additional weeks were needed to install the Schuco system. Ten weeks of this rework was done by the architect late in the design phase. The original frit pattern didn’t work with the HVAC system, so the architect had to redesign it in order to increase the shading coefficients. The additional 8 weeks of additional work needed to properly install the Schuco system was added directly to the schedule. It was determined by the project team that if the owner would have switched to the alternative curtain wall system the proposed installation times would have been roughly the same. The schuco system has more prefabrication time because it is a gasket system. The Kawneer system has a shorter prefabrication time, but also takes more time to install in the field because of the caulked joints. If the owner would have switched to the alternative system, not only could the 18 weeks of additional work been avoided but the prefabrication time could have been reduced by six to eight weeks.

I. How the Project Team Solved the Water Proofing Issue

After The project team realized there was potentially a large problem with the curtain wall they started coming up with solutions. During the shop drawings reviews they assessed the constructability sequencing of the curtain wall. They decided to implement two different solutions to the watertight issue.

First, in order to keep construction on schedule, a watertight wall was built behind the curtain wall system so that finishes could still be installed. Although this solution will cost the owner money to build the waterproof wall, it allowed finishes, which are on the projects schedule critical path, to still be installed on time. The project team found this method to be more cost effective than losing time one the schedule.

The second approach they took in solving the watertight issue with the curtain wall system was to wrap the blue skin into the building on all four sides (head/sill/both jambs). Then they installed Cavity closures made of stainless flashing (C, Z,L shaped) and then caulked any gaps left. This delineated the systems so that there wasn't any water from the masonry cavity running into the window system.

J. Summary / Conclusion

Because the architect did not want to change his design and the owner didn't want to bring the skin consultant on board up front, the project team had to build the curtain wall with the constructability issues listed above. If the owner would have taken some of the design and constructability changes proposed by Whiting-Turner, they could have eliminated some if not all of those issues. Liked stated previously, Whiting-Turner had to add over $400,000 of design changes to the project and 6 weeks onto the project schedule. If the owner would have brought the skin consultant onto the project at the design phase along with changing to either the YKK 750 series or Kawneer curtain wall systems Whiting-Turner mentioned, this issue could have been avoided.

VIII. Green Roof Design Analysis

A. Problem Identification

There were very few sustainable ideas implemented on the bayhealth medical center expansion. Green roof technology is beginning to emerge in the construction industry today as a way to not only make a building more environmentally friendly, but also as a way to provide savings to the owner in the long run. A green roof system is a great way to reduce storm water runoff, reduce the buildings heat island effect, and also reduce mechanical loads.

B. Research Goals

The goals for this analysis will be to study green roof technology, and then determine its cost effectiveness on this project. The buildings steel structure, both current and proposed addition, will also be studied to determine whether it can support the additional weight of a green roof system.

C. Methodology

- Analyze current and proposed steel structure
- Research various types of green roof systems
- Redesign current roof structure
- Discuss with owners rep about future additions

- Determine if a green roof system can be removed after installation and installed again
- Decide upon a way to move the green roof system
- Assess the cost and schedule implications of a green roof addition

D. Green Roof Introduction

A green roof is a type of roofing system that can be installed on a building's roof or any other flay surface. They are comprised of some type of vegetation and a growing medium. Green roofs have been around for centuries in countries such as Scandinavia. Green roofs, or what they considered sod roofs, were comprised of long strips of sod that were gathered from nearby grass meadows. These sod roofs were installed over birch bark (used for a waterproofing membrane) on top of heavy timber beams. The added insulation helped keep

Scandinavian houses warmer during the very cold winter months and cooler during the warmer months. There are two modern types of green roof systems, an intensive system and an extensive system.

E. Green Roof System Chosen

The green roof system that was chosen for this analysis is the standard extensive (4 inch) modules manufactured by GreenGrid systems. This type of system was chosen because of its modular design of 2'X 2' X 4" modules. A current industry issue with green roof systems is that since older systems weren't a modular design, when any maintenance needs to be performed large sections of the green roof would have to be removed and replaced, costing the owner money. Because of the GreenGrids modular design, small sections can be easily removed and replaced without any cost to the owner. The GreenGrid system is comprised of the following:

Module	**100% pre-consumer recycled high molecular weight polyethylene protected with UV inhibitor and stabilizers.**
Growth Media	**Proprietary engineered growth media blend of organic and inorganic components. Based on German FLL standards.**
Vegetation	**Perennials, grasses, or shrubs specifically selected for climate, hardiness zone, color, and size.**

F. Green Roof Structural Breadth Analysis

In order to check the feasibility of adding a green roof system to the bayhealth medical center this analysis will be done in two parts. The first part will be to examine the current roof structure and determine if it is adequate or what changes will be needed to be changed. The second part will be an analysis of the entire steel structure, both existing and proposed during phase three, to determine if it can withstand the additional load created by the green roof system. This was first part was done by examining the current roof structure and its loads. The current roof structure is comprised of:

- composite deck of 3-¼" inch lightweight concrete

- 18 gauge galvanized metal decking
- Tapered insulation ranging from 3” to an 1-1/2”
- 5/8 roof cover board
- Single ply EPDM roofing membrane

In order to perform this Structural analysis, the roof loads needed to be determined. The table to the right shows a summary of the roof loads used. The total roof load has found to be 94 psf (note because the dead load is less than the snow load only the snow load is used in determining the total load). The spans of the beams were determined to be 32’ for the two exterior bays and 26’ for the interior bay. The first check preformed was on the beams in each of the three bays (note all beams were considered simply supported and the bare beam capacity was used even though they are composite beams). The chart below summarizes the calculations for each of the bays beams. The LRFD method was used to determine these values.

Roof Loads (PSF)	
Live	**25**
Dead	**15**
Snow	**24**
Green Roof	**20**
CONC Slab	**24**
Total	**94**

	Bay One	Bay Two	Bay Three
Demension	**30'X32'**	**30'X26'**	**30'X32'**
Beam Size	**W18X35**	**W14X22**	**W30X108**
Beam Spacing	**10'**	**7.5'**	**10'**
Shear	**15.04 kip**	**9.17 kip**	**15.04 kip**
Shear Capacity	**159 kip**	**96 kip**	**488 kip**
Moment	**120.32 kip-ft**	**58.96 kip-ft**	**120.32 kip-ft**
Moment Capacity	**249 kip-ft**	**125 kip-ft**	**1300 kip-ft**

The next analysis preformed was determining if the columns were large enough to carry the additional load. A typical bay, which included columns K12 and L12, was used in determining these values. First the super imposed dead load was determined using the following numbers:

- slab 3 ¼" LW concrete on 18 gauge galvanized decking = 42psf
- Mechanical Equipment = 10 psf
- Beams and Girders = 5 psf
- Total = 57 psf

Next a Live load reduction was performed for each floor. For column K12 (interior column) a live load of 80 psf was chosen because of the adjacent corridor. The live load reduction formula:

$$L = L_0 * (.25 + \frac{15}{K_{tt} * A_t})$$

Where

A_t = Tributary area $A_t = 30' * \frac{32' * 26'}{2}$

K_{tt} = 4 (for a column)

$$L = 80 * (.25 + \frac{15}{4 * 870}$$

$$L = 40.34$$

- 40.34 > .4L_o (32) therefore live load reduction can be used for column K12

Now that the live load and dead load for column K12 has been determined, the loads on the column per floor can be determined using the following Equation.

$$R_U = \ 1.2D + 1.6L \ * A_t$$

Roof $$R_U = \ 1.2 \ 20 + 24 + 42 \ \ + .5(20) \ * 870$$

$$R_U = 98.48 \text{ kip}$$

Floor $$R_U = \ 1.2(57) + 1.6(40.34) \ * 870$$

$$R_U = 115.66 \ kip/floor$$

Roof	98.48 kip
10th	115.66 kip
9th	115.66 kip
8th	115.66 kip
7th	115.66 kip
6th	115.66 kip
5th	115.66 kip
4th	115.66 kip
3th	115.66 kip
2th	115.66 kip
1th	115.66 kip

$$P_U = 98.48 * 115.66(9)$$

$$P_U = 1139.43 \ kip$$

P_u<1650

Therefore with the addition of the green roof and the additional floors planned in phase three the interior columns would still be large enough to carry the additional load.

Similarly for column L12 (exterior column) a Live load reduction was performed for each floor. For column L12 (exterior column) a live load of 40 psf was chosen because of the adjacent offices. The live load reduction formula:

$$L = 40 * (.25 + \frac{15}{4 * 480})$$

$$L = 23.69$$

- 23.69 > .4L_o (16) therefore live load reduction can be used for column L12

$$R_U = \ 1.2D + 1.6L \ * A_t$$

Roof $R_U = \ 1.2 \ 20 + 24 + 42 \ + .5(20) \ * 480$

$R_U = 54.34$ kip

Floor $R_U = \ 1.2(57) + 1.6(23.69) \ * 480$

$R_U = 51.03\ kip/floor$

Roof	54.34 kip
10th	51.03 kip
9th	51.03 kip
8th	51.03 kip
7th	51.03 kip
6th	51.03 kip
5th	51.03 kip
4th	51.03 kip
3th	51.03 kip
2th	51.03 kip
1th	51.03 kip

P_U =(54.34)* 9(51.03)

$$P_U = 513.61\ kip$$

P_u<1340

Therefore with the addition of the green roof and the additional floors planned in phase three the exterior columns would still be large enough to carry the additional load.

Because the podium building had an extensive issues with an abnormally high water table on site the Foundation system was over engineered. Because of this fact, it was determined that the foundation system would be more than adequate to support the addition of the green roof.

G. Green Roof Mechanical Breadth Analysis

There are several benefits directly related to a buildings mechanical system with an addition of a green roof system. A green roof can improve a buildings overall energy efficiency, by reducing its overall heat transfer. In order to perform this analysis, the R values of all roofing materials had to be determined. These values are summarized below:

R values for original roof

- 3 ¼" LW concrete (80psf) R = 2.3
- 18 gauge galvanized decking R = 0
- 3" Rigid insulation: R = 30
- 5/8 roof cover board R =.85

U value: 1/ΣR = .030166

With green roof

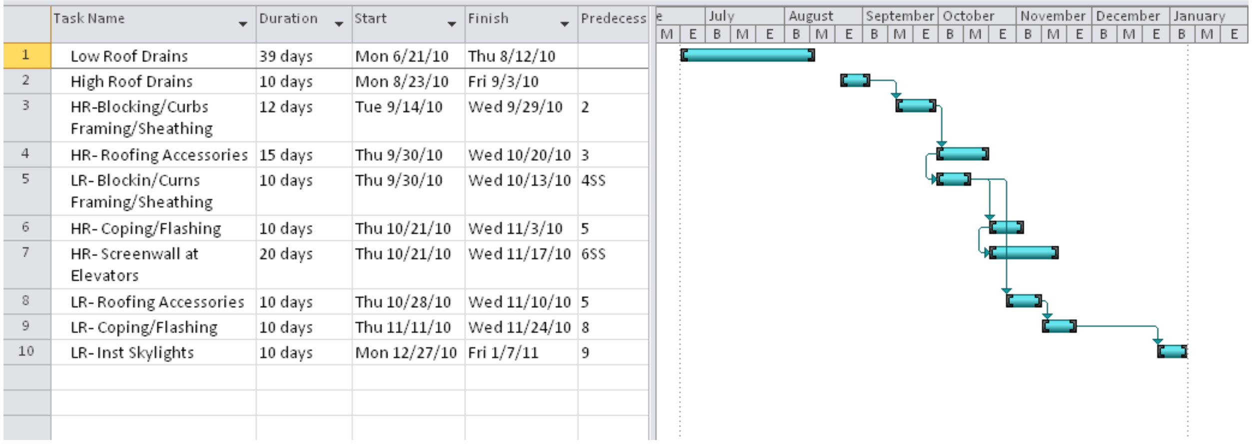
- 3 ¼" LW concrete (80psf) R = 2.3
- 18 gauge galvanized decking R = 0
- 3" Rigid insulation: R = 30
- 5/8 roof cover board R =.85
- Green roof R = 5

U value: 1/ΣR =.0262123

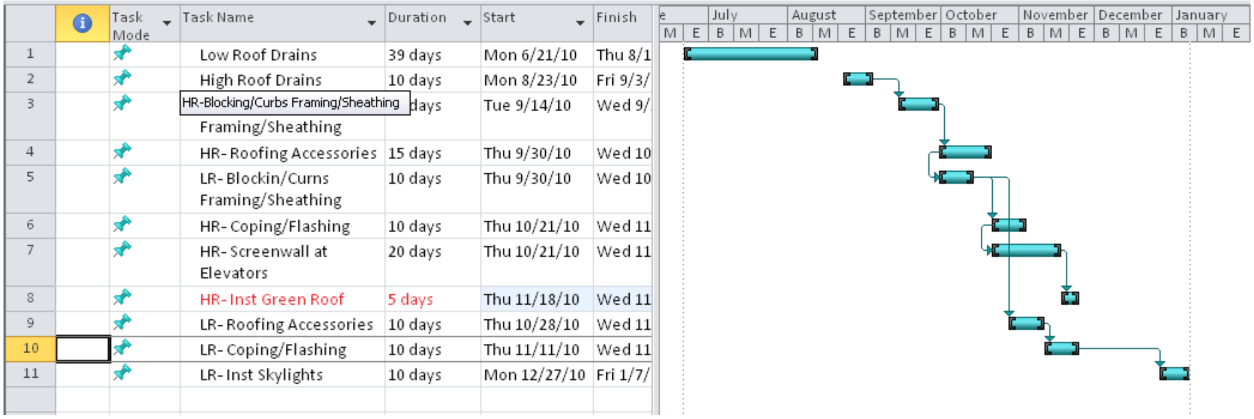
When these R values were entered into trace software and a basic model was designed for each of the cases, the required cooling capacity changed from 35.4 tons to 35 tons. After running this analysis it was determined that the added R value of the green roof is small in comparison to the overall R value of the roof system, which in turn caused a small effect on the roofing systems overall U value.

H. Schedule & Cost Impacts

There are several variables that impact the installation times of a green roof system. According to the manufacture, the average lead time for the proposed system is six to eight weeks. This can vary greatly depending on the required medium growth denoted in the specifications. Crew size also has a direct impact on installation times. A typical crew of six to eight people can install roughly 6,000 sq ft per an eight hour day. Crane availability is also a large determining factor in installation times. Given that the size of the proposed green roof is 28,000 sq ft, it was determined that it would require 5 working days to fully install the green roof system. As shown in the two schedules below, the addition of the green roof will add a total of 5 days to the roofing schedule. This addition of five days won't impact the overall project schedule because it is not located on the projects critical path.

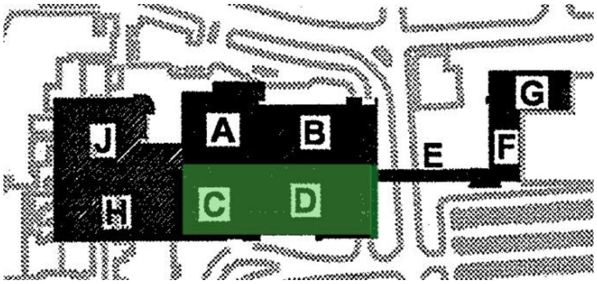


	Task Name	Duration	Start	Finish	Predecess
1	Low Roof Drains	39 days	Mon 6/21/10	Thu 8/12/10	
2	High Roof Drains	10 days	Mon 8/23/10	Fri 9/3/10	
3	HR-Blocking/Curbs Framing/Sheathing	12 days	Tue 9/14/10	Wed 9/29/10	2
4	HR- Roofing Accessories	15 days	Thu 9/30/10	Wed 10/20/10	3
5	LR- Blockin/Curns Framing/Sheathing	10 days	Thu 9/30/10	Wed 10/13/10	4SS
6	HR- Coping/Flashing	10 days	Thu 10/21/10	Wed 11/3/10	5
7	HR- Screenwall at Elevators	20 days	Thu 10/21/10	Wed 11/17/10	6SS
8	LR- Roofing Accessories	10 days	Thu 10/28/10	Wed 11/10/10	5
9	LR- Coping/Flashing	10 days	Thu 11/11/10	Wed 11/24/10	8
10	LR- Inst Skylights	10 days	Mon 12/27/10	Fri 1/7/11	9



	ℹ	Task Mode	Task Name	Duration	Start	Finish
1		📌	Low Roof Drains	39 days	Mon 6/21/10	Thu 8/1
2		📌	High Roof Drains	10 days	Mon 8/23/10	Fri 9/3/
3		📌	HR-Blocking/Curbs Framing/Sheathing Framing/Sheathing	days	Tue 9/14/10	Wed 9/
4		📌	HR- Roofing Accessories	15 days	Thu 9/30/10	Wed 10
5		📌	LR- Blockin/Curns Framing/Sheathing	10 days	Thu 9/30/10	Wed 10
6		📌	HR- Coping/Flashing	10 days	Thu 10/21/10	Wed 11
7		📌	HR- Screenwall at Elevators	20 days	Thu 10/21/10	Wed 11
8		📌	HR- Inst Green Roof	5 days	Thu 11/18/10	Wed 11
9		📌	LR- Roofing Accessories	10 days	Thu 10/28/10	Wed 11
10		📌	LR- Coping/Flashing	10 days	Thu 11/11/10	Wed 11
11		📌	LR- Inst Skylights	10 days	Mon 12/27/10	Fri 1/7/

The typical cost of the proposed green roof is $10-$15 per square feet, which includes delivery. The typical cost of installation, including crane rental, is between $3-$6 per square feet, depending on several factors such like roof height parapet wall height, staging areas, etc. The green roof would cover approximately 28,305 square feet of section C and D of the pavilion building. So the projected cost of purchasing, installation and delivery of the green roof is $462,000.



I. Conclusions & Recommendations

Because the podium buildings structural system is already oversized in anticipation of adding additional stories during the phase 3 expansion, the current and proposed structural system is more than adequate to support the addition of a green roof.

Although through using Trace software to model the mechanical loads on the podium building showed a negligible effect on the mechanical systems, there are other possible benefits to adding a green roof. Other factors like roof shading and plant transpiration can provide additional positive effects to the buildings mechanical systems.

Even though the only added cost of adding a green roof system to the podium building is the cost of the system itself and the installation of the system, it still will cost the owner $462,000. Because one of the major concerns for the project is cost, this isn't a worthwhile addition to the podium building during the phase two expansion. If the owner wanted to pursue the addition of a green roof system during the phase three expansion of the podium building, the existing structural system is adequate enough to withstand the added load. It could also prove to have additional savings because of lower mechanical loads and also a longer lifetime of standard EPDM roofing.

IX. Prefabrication of Building Systems Analysis

A. Problem Identification

Because of the extensive amount of MEP systems needed in a hospital, a lot of time and money is spent installing these systems. Since these systems are so important to the overall building, their installation is usually on the schedules critical path. Because cost and quality are paramount to the bayhealth medical center expansion owner, the installation of these systems must be watched over diligently. The installation of these systems is not only time consuming and expensive, but can also be very problematic.

B. Research Goals

The goals for this analysis will be to determine a potential area of the building to implement prefabrication, and to evaluate the possible time and cost savings to the project. Also, what systems can take advantage of prefabrication will be determined.

C. Methodology

- Research prefabrication technologies in the industry
- Identify similar project that has implemented prefabrication
- Contact industry specialists
- Determine the most effective areas for prefabrication
- Determine what systems can be prefabricated
- Calculate the time and cost saved by prefabrication

D. Prefabrication in the Industry

Prefabrication is a technique that is just starting to take hold in the construction industry in the United States. Projects like the 484,000 square foot Miami Valley Hospital

Southeast Addition located in Dayton, Ohio are prime examples of the large benefits that can be obtained from prefabrication. Because of a 14 week delay in the schedule caused by having to pull out 10 footings and redesign the entire foundation system, 178 patient rooms and 120 overhead corridor racks were prefabricated to keep the schedule on track. Not only did this save two months off of the schedule, but also 1% to 2% off of the total 152 million dollar expansion. According to Mart Corrado, the project executive for field operations for Skanska USA building Inc., if the decision to do prefabrication was made at the beginning of the project an estimated four to six months could have been cut off the schedule. In order to achieve the advantages of prefabrication it requires subcontractors to be on board much earlier than usual, because important decisions like the layout of a patient room must be made four to six months earlier than on a typical project. According to Brian Braaksma, president of Korda Engineering, who was the MEP consultant on the project, "*Key to the success of the strategy was the use of building information modeling. For the work, there were separate design and construction BIMs. "Using 3D layout during design" aided the modeling of the whole assembly.*"

In order to make sure that the prefabricated rooms were exactly what the owner wanted, room mock ups were made down to the location of electrical outlets. Simulations were even used to give the owner a better picture of the final room layout. The addition was broken down into five patient floors that were then broken down into three wings. Each wing was then broken down into a 16 foot wide corridor and 11 patient rooms. Each room was designed to be the exact same, and the corridor was designed into two eight foot sections. Not only did this method make the prefabrication repetitious but also reduced above ceiling clutter.

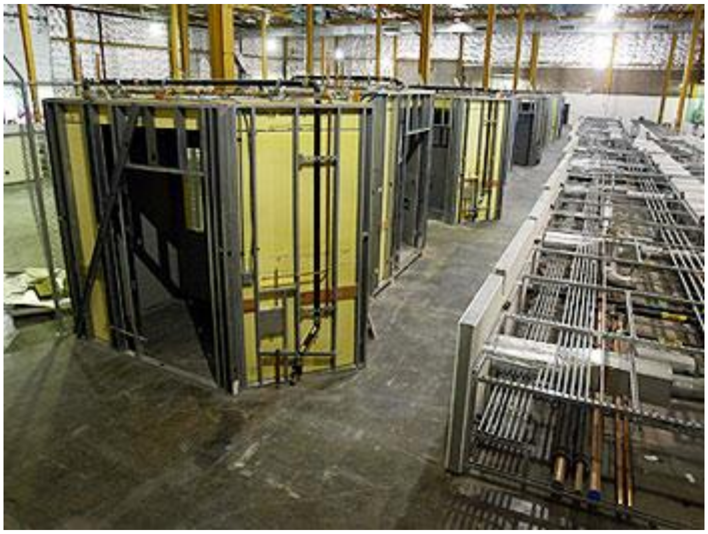


Figure 2: Prefabrication Warehouse

There were several lessons that Skanska took away from the Miami Valley Hospital expansion. First, that timing is very important when considering prefabrication on any project. Also, Prefabrication production should be timed correctly so that each piece can be shipped to the jobsite picked off the truck and installed as soon as it is finished. Another lesson that the project team learned was that other items on the schedule, such as getting the building watertight, must be taken into consideration.

E. Schedule Savings Comparison

According to information given by Marty Corrado, prefabrication can raise production rates by as much as 300% for some trades. In order to apply this to the bayhealth medical center, sector A_1 on the first floor was analyzed. Sector A_1 was chosen because of its repetitive room layout of exam and trauma rooms, and also for its high level of MEP work. As can be determined from the picture to the right there is an estimated 1,352 linear feet of partition wall in sector A_1, with 392 linear feet of partition wall being in the yellow highlighted sections. This accounts for 30% of the total linear feet of partition walls in sector A_1. By interpolation from the project schedule, it was determined that it took a total duration of 150 working days to install these walls to completion, with exception of drywall. The chart below summarizes each line item of the schedule that was used to determine this value.

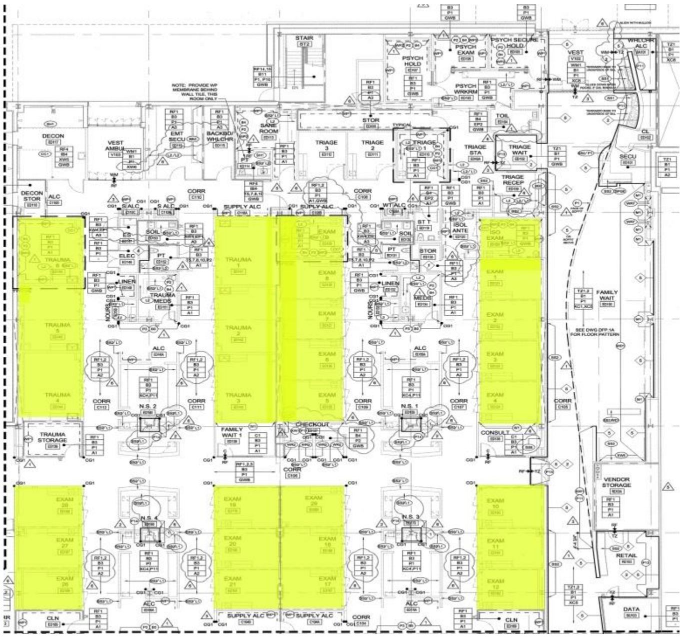


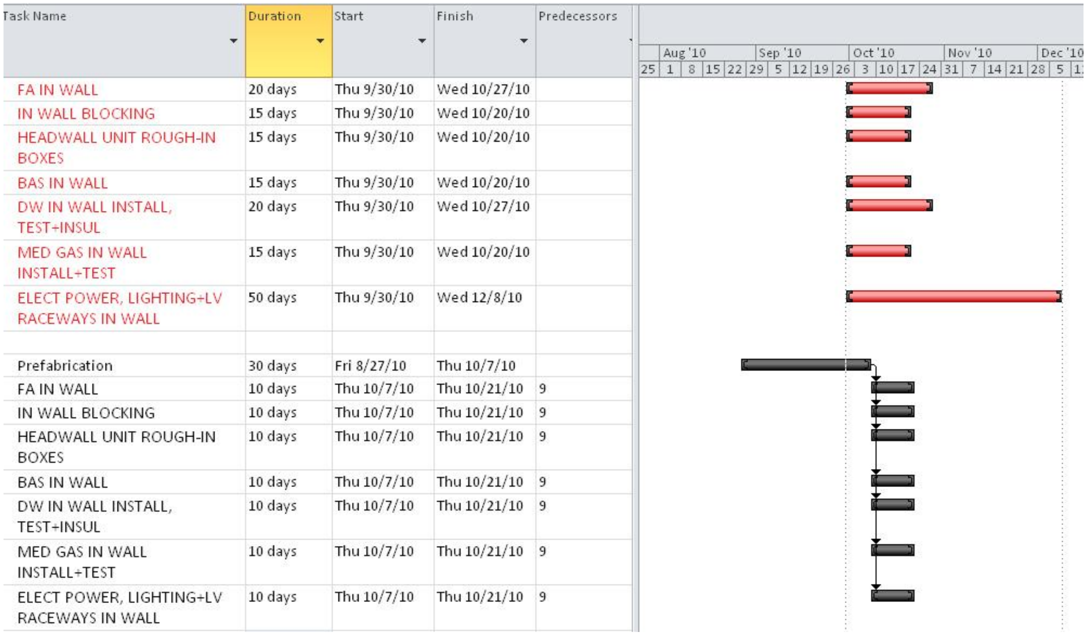
Figure 3: Sector A Areas of Prefabrication

Activity Description	Duration
FA IN WALL	20
IN WALL BLOCKING	15
HEADWALL UNIT ROUGH-IN BOXES	15
BAS IN WALL	15
DW IN WALL INSTALL, TEST+INSUL	20
MED GAS IN WALL INSTALL+TEST	15
ELECT POWER, LIGHTING+LV RACEWAYS IN WALL	50
Total Days	150

Using the value of 30% that was determined earlier it can be concluded that it took 45 working days to completely install the partition walls in the exam and trauma rooms highlighted above. In order to conservatively apply the findings from the Miami Valley Hospital, The production rate was increased to 125%. Applying the increase in production it was found that a total 9 working days can be saved in area A_1. The chart below shows the possible working day savings throughout the bayhealth medical center:

	Original Duration	125% Production Rate Duration	Potential Working Days Savings
Sector A_1	45 days	36 days	9 days
Sector C_1	15 days	12.5 days	2.5 days
Sector D_1	17 days	3 days	3 days
Sector D_2	17 days	3 days	3days
		Total Working Day Savings	17.5 days

Also because the installation of the prefabricated wall units is much faster, the duration of in wall activities on the schedule is reduced from 50 days down to 10 days. Below is a summary schedule showing the possible schedule savings to area A_1. The activities written in red are the original activity durations in area A_1, also note that all of these activities are located on the projects critical path.



Task Name	Duration	Start	Finish	Predecessors
FA IN WALL	20 days	Thu 9/30/10	Wed 10/27/10	
IN WALL BLOCKING	15 days	Thu 9/30/10	Wed 10/20/10	
HEADWALL UNIT ROUGH-IN BOXES	15 days	Thu 9/30/10	Wed 10/20/10	
BAS IN WALL	15 days	Thu 9/30/10	Wed 10/20/10	
DW IN WALL INSTALL, TEST+INSUL	20 days	Thu 9/30/10	Wed 10/27/10	
MED GAS IN WALL INSTALL+TEST	15 days	Thu 9/30/10	Wed 10/20/10	
ELECT POWER, LIGHTING+LV RACEWAYS IN WALL	50 days	Thu 9/30/10	Wed 12/8/10	
Prefabrication	30 days	Fri 8/27/10	Thu 10/7/10	
FA IN WALL	10 days	Thu 10/7/10	Thu 10/21/10	9
IN WALL BLOCKING	10 days	Thu 10/7/10	Thu 10/21/10	9
HEADWALL UNIT ROUGH-IN BOXES	10 days	Thu 10/7/10	Thu 10/21/10	9
BAS IN WALL	10 days	Thu 10/7/10	Thu 10/21/10	9
DW IN WALL INSTALL, TEST+INSUL	10 days	Thu 10/7/10	Thu 10/21/10	9
MED GAS IN WALL INSTALL+TEST	10 days	Thu 10/7/10	Thu 10/21/10	9
ELECT POWER, LIGHTING+LV RACEWAYS IN WALL	10 days	Thu 10/7/10	Thu 10/21/10	9

The large time savings of 40 schedule days occurs because theses activities are taken directly off the projects critical path. Installation of the prefabricated walls is much faster than performing traditional rough-in in the field. Below is a table summarizing the potential total schedule savings:

	Original Schedule Duration	**Prefabrication Schedule Duration**	**Potential Schedule Savings**
Sector A_1	**50 days**	**10 days**	**40 days**
Sector C_1	**15 days**	**5 days**	**10 days**
Sector D_1	**15 days**	**5 days**	**10 days**
Sector D_2	**15 days**	**5 days**	**10 days**
		Total schedule savings	**70 days**

F. Cost Savings Comparison

It was determined that 1% to 2% of the total project cost was saved because of prefabrication on the Miami Valley Hospital. Because of a lack of data showing where the cost savings comes from, it is difficult to pinpoint the exact savings. The most obvious area that there could be savings is the reduction of man hours. As stated above a total of 17.5 working days can be saved by implementing prefabrication.

Also a shorter overall project schedule can save a significant amount on the general conditions costs on a project. As stated above, an estimated 70 days can be saved off of the total project duration. According to a general conditions estimate, the total general condition cost on the bayhealth medical center was $8,702,302.00 over the 148 week schedule. This breaks down to a general condition cost of $58,800 per each scheduled week. Taking the proposed 70 weeks off of the project schedule, it can be concluded that 14 weeks or $823,200 can be saved on general condition costs.

G. Conclusions & Recommendations

When preformed correctly there is a long list of benefits to prefabrication. Not only is there a cost savings to the owner but a higher quality product is produced overall. Because prefabrication is performed in such a controlled environment there are fewer issues with worker injuries and less waste. As shown above there is a potential savings of $823,200 off of the general conditions cost, as well as 17.5 working days savings But, with the implementation of prefabrication it is essential to not only have the entire project team on board at the design phase of the project, but also design the schedule to allow for the accelerated installation of MEP installation. Because of cost and schedule are two things the owner of the bayhealth medical center is concerned with, prefabrication would be an effective tool on this project.

X. 3-D Coordination Analysis

A. Problem Identification

BIM seems to be one of the most talked about topics in the construction industry today. It is completely revolutionizing how construction projects are being done today. Using even the basic concepts of BIM, like clash detection and 3D coordination, can greatly reduce the time and money it takes to ensure that building systems can be properly installed, and reduce the number of change orders and field problems that occur due to improper coordination.

B. Research Goals

The goal of this analysis will be to show how the use of 3D coordination can help streamline and simplify the coordination process. By identifying areas of MEP construction that could be problematic, a reasonable analysis of the benefits of implementing 3D coordination will be determined.

C. Methodology

- Review the BIM Project Execution Planning Guide created by Penn State
- Identify similar projects that have implemented clash detection – 3D coordination
- Evaluate the cost and schedule impacts of clash detection/3D coordination.
- Summarize the advantages and disadvantages of implementing clash detection/3D coordination on a project

D. 3-D Coordination Technology

For decades the coordination of the MEP systems has done in the same 2-D manner. All of the trade's drawings were compiled into one drawing and then visually inspected to find clashes in the buildings systems. This process of 2-D coordination not only takes a lot of time, but ultimately clashes will be missed. These clashes that are missed not only generate change orders for the project team, but also negatively impact the schedule and cost the owner more money. New 3-D technology has emerged within the industry in the last few years that is simplifying and streamlining the coordination process while making it cheaper for all parties involved. Because the bayhealth medical center is such an interact project utilizing 3 – D coordination could be a valuable tool to save both time and money.

E. Summary of Implementing 3 – D coordination

This section will describe the general method of implementing 3 –D coordination onto the bayhealth medical center from the design phase to project completion by following the BIM execution plan developed by The Pennsylvania State University and also 3D and 4D modeling for design and construction: issues and lessons learned case study.

Because there are more advantages to modeling in 3 - D for some trades that others can't as readily take advantage of, a varying level of experience is usually found. Trades like sheet metal and plumbing on average tend to have the largest experience with 3 – D coordination because of the potential cost savings from prefabrication. Other trades, such as electrical and Sprinkler installers have a less experience with the technology, because of less of a possibility for prefabrication. Even though some trades benefit more from 3 –D coordination, it is possible that all trades can gain something out of the process.

In order to properly implement 3 – D coordination, there are many things that need to be organized and a lot of responsibilities by each party involved. The earlier in a project it is decided that3 – D coordination techniques will be used, the smoother the process will be. It is a common practice to preapproved subcontractors to bid that have the experience and capabilities to produce the required deliverables. Additionally it is important to include the extra initial work needed by each subcontractor in their specific scope of work. It was determined according to the case study discussed above, that there are 10 steps to effective implantation of 3 –D coordination on a project:

1. Identify the Potential Uses of the 3D Models
2. Identify the Modeling Requirements

3. Establish the Drawing Protocol
4. Establish a Conflict Resolution Process
5. Develop a Protocol for Addressing Design Questions
6. Develop Discipline-specific 3D Models
7. Integrate Discipline-specific 3D Models
8. Identify Conflicts between Components/Systems
9. Develop Solutions for the Conflicts Identified
10. Document Conflicts and Solutions

1. Identify the Potential Uses of the 3D Models

The project team must discuss the potential use of the model. Because the 3 – D model can be used for activities such as cost estimating, shop drawings, and group visualization, it is important to know what their exact intended uses will be. The use of the model dictates the modeling requirements, and also the modeling techniques and the level of detail.

2. Identify the Modeling Requirements

Identifying who is responsible for each scope of work is paramount when performing 3- D coordination. The project team must also establish the level of detail and scope of the model. A cost and benefit list should be developed, to establish what should and shouldn't be modeled. As an example, rebar could potentially be modeled to help with the procurement process, but this probably wouldn't prove to be cost effective. The next item that must be addressed is identifying how each of the separate models will be integrated into one model. Lastly a schedule of the entire modeling sequence, from design of the models to the coordination process, must be created and approved by all involved parties.

3. Establish Drawing Protocol

To ensure that the integration of the individual models is a smooth process, there are certain protocols that must be established. A common reference point needs to be established in order to ease the process of layering models. A specific file naming convention needs to be approved and established by all involved parties. It is also important to institute a color scheme, decide how objects should be layered in the model, and have a version control system in place.

4. Establish a conflict Resolution Process

The specific software that the 3 - D coordination will be performed in must be chosen. Software such as Autodesk and Navisworks are two common choices. After a software package is chosen, a way to share drawings needs to be recognized. Another step in the conflict resolution process is deciding a meeting time and the general itinerary of each coordination meeting. The last step in this process is to identify a responsible party to facilitate the coordination meetings.

5. Develop a Protocol for addressing Design Questions

This step is only necessary if the contractor is in charge of developing of the 3 – D models. There must be a system in place so that everyone working with the models can quickly communicate with anyone else that is part of the coordination process. Traditionally this has been done using the RFI technique, but was found to be very inefficient and time consuming.

6. Develop Discipline Specific Models

After each of the design specific models have been created, combined, and the coordination process is started, each of the involved parties must have access to the coordination model.

7. Integrate Discipline Specific 3 – D Models

Each party responsible for a 3 – D model must download and integrate their updated models into the coordination model before each coordination meeting.

8. Identify Conflicts between Components and Systems

During the coordination process both hard conflicts, conflicts that are between building components, and soft conflicts, interferences between building components and access spaces or violations of clearance, must be discovered and addressed.

9. Identify Solution for the Conflicts Identified

After a conflict has been discovered, the coordination team, as a whole, should develop a workable solution that satisfies all parties involved in the clash.

10. Document Conflicts and Solution

Every part the conflict, the proposed solution, the parties involved, the systems involved, and the current file version should be identified and documented. It is also encouraged to record the meeting date and all parties involved in each meeting.

F. Benefits of Using 3-D Coordination

There are many benefits of using 3-D coordination on building projects like bayhealth. There are several initial and long term benefits to using 3-D coordination listed below:

- The owner is able to review designs of the mechanical spaces before construction starts
- The owner is able to approve room layouts before construction starts
- Less RFI's during building construction
- Each trade has more of a potential for prefabrication
- The owner is delivered a higher quality finished product
- As built model can be given to the owner for their own use
- It is easier to track the coordination process
- There is an increase of productivity
- A possible decreas in construction times
- Less skilled labor is needed during systems rough in
- There is less rework needed
- There is less cost growth

G. Cost and Schedule Implications

The costs of implementing 3 – D coordination on a project can be very hard to determine. According to Project members on the bayhealth medical center, there are no additional costs associated with implementing 3 – D coordination because the costs on a project are essentially moved forward from the installation to the design phase of a project. It takes longer to do 3 – D coordination because of the amount of detail that must be put into the models, but the issues that comes from traditional 2 – D coordination, such as RFI's, don't slow the project down and cost more money.

H. Conclusion and Recommendations

Although there is no way to numerically show that 3 – D coordination is better than traditional 2 – D coordination, it has been shown to have noticeable benefits. 3 – D coordination requires that at the beginning of a project all key players must be on board and work together. Not only must everyone be on board, but it must be determined what each individual's responsibilities are at all times during the coordination process.

Because not only is the schedule greatly affected, but many of the costs associated with coordination won a project are accelerated, the earlier that a project decides to use 3 – D coordination the easier it will be and the larger the potential to save money. With taking these and other things into consideration, a project like the bayhealth medical center can greatly benefit by using 3 – D coordination process described above. Because of the complicated type of MEP work being performed in the bayhealth medical center, and the possible benefits to performing 3 – D coordination it would be a valuable method to pursue.

XI. Final Conclusions

The bayhealth medical center's 10 year strategic plan for construction was put in place in order to provide for both current and future needs to the hospital. The three biggest concerns the bayhealth medical center's owners had with the phase two expansions were quality, cost and schedule. It was from these 3 values that each of the four analyses in this paper was chosen. The issues encountered waterproofing the curtain wall system was chosen to show how a simple issue during the design phase of a project can potentially cost the owner time and money. The green roof addition was chosen to not only provide the owner with prospective cost savings but to also provide the owner with a higher end product. Since the owner of the bayhealth medical center is concerned with quality and schedule duration, prefabrication was chosen because of its potential schedule savings and higher quality. Lastly, a look into 3 – D coordination was analyzed as a potential cost savings to the owner.

Through the analysis of the curtain wall discussed above it was determined that if because the architect did not want to change his design and the owner didn't want to bring the skin consultant on board up front, the project team had to build the curtain wall with certain constructability issues. If the owner would have taken some of the design and constructability changes proposed by Whiting-Turner, they could have eliminated some if not all of those issues avoided.

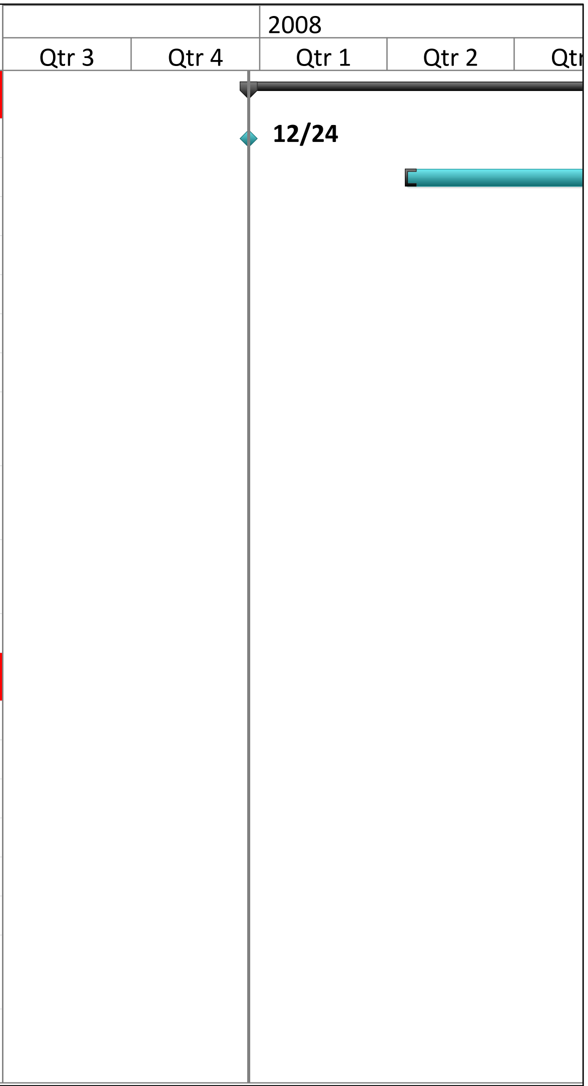
Through the analysis of the green roof addition discussed above it was determined that even though the only added cost of adding a green roof system to the podium building is the cost of the system itself and the installation of the system, it still will cost the owner $462,000. If the owner wanted to pursue the addition of a green roof system during the phase three expansion of the podium building, the existing structural system is adequate enough to withstand the added load. It could also prove to have additional savings because of lower mechanical loads and also a longer lifetime of standard EPDM roofing currently installed.

Through the analysis of prefabrication discussed above it was determined that when preformed correctly there is a long list of benefits to prefabrication. Not only is there a cost savings to the owner but a higher quality product is produced overall. A savings of 1% could be a possible $650,000 savings on the bayhealth medical center. Because of cost and schedule are two things the owner of the bayhealth medical center is concerned with, prefabrication would be an effective tool on this project.

Through the analysis of 3 – D coordination discussed above it was determined that 3 – D coordination requires that at the beginning of a project all key players must be on board and work together. Not only must everyone be on board, but it must be determined what each individual's responsibilities are. A project like the bayhealth medical center can greatly benefit by using 3 – D coordination, because of its complicated MEP work. The possible benefits to performing 3 – D coordination would be a valuable method to pursue for the bayhealth medical center.

XII. Appendix A: Detailed Project schedule

ID	ℹ	Task Mode	Task Name	Duration	Start	Finish
1		⇨	**Foundations**	**873 days**	**Mon 12/24/07**	**Wed 4/27/11**
2		📌	Project Start	0 days	Mon 12/24/07	Mon 12/24/07
3		📌	Site Utilities Relocation	181 days	Mon 4/14/08	Mon 12/22/08
4		📌	Bulk Excavation	480 days	Tue 10/7/08	Mon 8/9/10
5		📌	Auger Cast Piles	92 days	Thu 11/13/08	Fri 3/20/09
6		📌	Sections C/A Elevator Pits	10 days	Tue 9/29/09	Mon 10/12/09
7		📌	Section A Sump Pits	7 days	Mon 10/5/09	Tue 10/13/09
8		📌	Section A Spread Footings	40 days	Mon 10/26/09	Fri 12/18/09
9		📌	Section D Foundation Walls	64 days	Mon 10/26/09	Thu 1/21/10
10		📌	Section A Foundation Walls	31 days	Mon 11/2/09	Mon 12/14/09
11		📌	Section C Foundation Walls	25 days	Mon 12/21/09	Fri 1/22/10
12		📌	Storm/Sanitary Lines	409 days	Mon 1/12/09	Thu 8/5/10
13		📌	**Structure**	**264 days**	**Mon 10/5/09**	**Thu 10/7/10**
14		📌	SOG	176 days	Mon 10/5/09	Mon 6/7/10
15		📌	Structural Steel	151 days	Mon 2/15/10	Mon 9/13/10
16		📌	BackFill	129 days	Fri 4/9/10	Wed 10/6/10
17		📌	Slab On Deck Area D	90 days	Mon 4/26/10	Fri 8/27/10
18		📌	Slab On Deck Area C	102 days	Tue 6/22/10	Wed 11/10/10
19		📌	Slab On Deck Area A	21 days	Fri 3/19/10	Fri 4/16/10
20		📌	Spray On Fireproofing Section A	37 days	Mon 5/10/10	Tue 6/29/10
21		📌	SprayOn Fireproofing Section D	107 days	Mon 5/24/10	Tue 10/19/10



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Summary	▬	Inactive Summary	▭	Finish-only	]
Project Summary	▬	Manual Task	▬	Deadline	⬇
External Tasks	▬	Duration-only	▬	Progress	▬

ID	ℹ	Task Mode	Task Name	Duration	Start	Finish			2008		
							Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr
22		📌	Spray On FireProofing Section C	65 days	Sat 7/10/10	Thu 10/7/10					
23		📌	Building Enclosure	163 days	Mon 9/13/10	Wed 4/27/11					
24		📌	Enclosure Area D	108 days	Mon 9/13/10	Wed 2/9/11					
25		📌	Enclosure Area C	187 days	Tue 8/10/10	Wed 4/27/11					
26		📌	Enclosure Area A	164 days	Mon 5/10/10	Thu 12/23/10					
27		📌	Area C/D Roofing	146 days	Mon 6/21/10	Mon 1/10/11					
28		📌	Area C Low Roofing	101 days	Mon 6/21/10	Mon 11/8/10					
29		📌	Area A Roofing	102 days	Tue 6/1/10	Wed 10/20/10					
30		📌	Basement Permanent Power	197 days	Mon 6/28/10	Tue 3/29/11					
31		📌	Pavilion Emergency Power	0 days	Thu 4/7/11	Thu 4/7/11					
32		📌	Area A Basement	386 days	Tue 4/20/10	Tue 10/11/11					
33		📌	Partition Layout	33 days	Mon 3/29/10	Wed 5/12/10					
34		📌	Stormwater Rough-In	62 days	Tue 4/20/10	Wed 7/14/10					
35		📌	HVAC Rough-In	137 days	Tue 4/20/10	Wed 10/27/10					
36		📌	Sprinkler Rough-In	3 days	Mon 6/7/10	Wed 6/9/10					
37		📌	Ductwork Branches	100 days	Thu 6/10/10	Wed 10/27/10					
38		📌	Plumbing In Wall / Testing	61 days	Wed 7/14/10	Wed 10/6/10					
39		📌	Electrical Rough-In	15 days	Thu 9/30/10	Wed 10/20/10					
40		📌	Punch List	13 days	Fri 9/23/11	Tue 10/11/11					
41	▦	⇨	Fitout Of Mech Room BU12	334 days?	Mon 6/7/10	Thu 9/15/11					
42		📌	Sanitary/storm Water Pipping	132 days	Tue 4/20/10	Wed 10/20/10					

Project: Project schedule.mpp
Date: Wed 10/27/10

Task	▬	External Milestone	◆	Manual Summary Rollup	▬
Split	┈	Inactive Task	▭	Manual Summary	▬
Milestone	◆	Inactive Milestone	◇	Start-only	[
Summary	▬	Inactive Summary	▭	Finish-only	]
Project Summary	▬	Manual Task	▬	Deadline	⬇
External Tasks	▬	Duration-only	▬	Progress	▬

ID	ℹ	Task Mode	Task Name	Duration	Start	Finish	Qtr 3	Qtr 4	2008 Qtr 1	Qtr 2	Qtr
43		📌	sprinkler Systems	108 days	Mon 6/7/10	Wed 11/3/10					
44		📌	Ductwork Install	128 days	Tue 6/8/10	Thu 12/2/10					
45		📌	House Keeping Pads	53 days	Thu 6/17/10	Mon 8/30/10					
46		📌	Medical Gas Rough-In	153 days	Thu 9/30/10	Mon 5/2/11					
47		📌	Set HVAC Equip	153 days	Thu 9/30/10	Mon 5/2/11					
48		📌	Fitout HVAC Piping	153 days	Thu 9/30/10	Mon 5/2/11					
49		📌	Fitout of Fire Alarm System	76 days	Tue 3/8/11	Tue 6/21/11					
50		📌	Punch List	41 days	Thu 7/21/11	Thu 9/15/11					
51		⇨	**Basement Fitout Mech Room BU002**	**249 days**	**Thu 6/24/10**	**Tue 6/7/11**					
52		📌	house Keeping Pads	75 days	Thu 6/24/10	Wed 10/6/10					
53		📌	Duct Work	98 days	Mon 6/28/10	Wed 11/10/10					
54		📌	Sprinkler System	93 days	Mon 6/28/10	Wed 11/3/10					
55		📌	AHU set	70 days	Thu 7/1/10	Wed 10/6/10					
56		📌	In wall MEP Rough-In	15 days	Thu 9/30/10	Wed 10/20/10					
57		📌	Fire Alarm System	56 days	Tue 3/22/11	Tue 6/7/11					
58		📌	Punchlist	10 days	Thu 7/14/11	Wed 7/27/11					
59		⇨	**Area C/D/A Basement Corridor Fitout**	**304 days**	**Mon 8/16/10**	**Thu 10/13/11**					
60		📌	Ductwork	65 days	Mon 8/16/10	Fri 11/12/10					
61		📌	Sprinkler System Rough-In	55 days	Mon 8/23/10	Fri 11/5/10					
62		📌	Mech Equip Pipe/Duct	83 days	Thu 9/30/10	Mon 1/24/11					
63		📌	Above Ceiling Rough-In	27 days	Fri 12/3/10	Mon 1/10/11					
64		📌	Fitout Fire Alarm	56 days	Tue 3/29/11	Tue 6/14/11					
65		📌	Punchlist	20 days	Fri 9/16/11	Thu 10/13/11					

Project: Project schedule.mpp
Date: Wed 10/27/10

Task	▬	External Milestone	◆	Manual Summary Rollup	▬
Split	┈	Inactive Task	▭	Manual Summary	▬
Milestone	◆	Inactive Milestone	◇	Start-only	[
Summary	▬	Inactive Summary	▭	Finish-only	]
Project Summary	▬	Manual Task	▬	Deadline	⇩
External Tasks	▬	Duration-only	▬	Progress	▬

ID	ℹ	Task Mode	Task Name	Duration	Start	Finish			2008		
							Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qt
66		⇨	**1st Floor Fitout Section A**	**565 days**	**Thu 10/8/09**	**Thu 12/8/11**					
67		📌	Ductwork	85 days	Thu 7/1/10	Wed 10/27/10					
68		📌	Sprinkler Rough-In	73 days	Mon 8/9/10	Wed 11/17/10					
69		📌	Elect Power/ Light Fixtures	56 days	Tue 3/29/11	Tue 6/14/11					
70		📌	Casework rooms	30 days	Thu 4/7/11	Wed 5/18/11					
71		📌	Device Fitout	20 days	Tue 4/12/11	Mon 5/9/11					
72		📌	Inspection/ Close Up	26 days	Tue 5/10/11	Tue 6/14/11					
73		📌	Plumbing	52 days	Tue 5/10/11	Wed 7/20/11					
74		📌	Fitout Finishes	82 days	Wed 6/1/11	Thu 9/22/11					
75		📌	Punchlist	71 days	Thu 7/28/11	Thu 11/3/11					
76		⇨	**1st Floor Section C**	**565 days**	**Thu 10/8/09**	**Thu 12/8/11**					
77		📌	Ductwork Install	95 days	Thu 7/1/10	Wed 11/10/10					
78		📌	Partition Layout	20 days	Mon 8/9/10	Fri 9/3/10					
79		📌	Sprinkler Rough-In	73 days	Mon 8/9/10	Wed 11/17/10					
80		📌	Power/Lighting Above ceiling Rough-In	68 days	Mon 8/16/10	Wed 11/17/10					
81		📌	Punchlist	49 days	Thu 8/4/11	Tue 10/11/11					
82		⇨	**1st Floor Fitout Diagnostic Imaging Suite**	**565 days**	**Thu 10/8/09**	**Thu 12/8/11**					
83		📌	CT Scan Equip	265 days	Thu 10/8/09	Wed 10/13/10					
84		📌	X-Ray Equip	265 days	Thu 10/8/09	Wed 10/13/10					
85		📌	Partiton Layout	4 days	Sat 10/9/10	Wed 10/13/10					

Project: Project schedule.mpp
Date: Wed 10/27/10

Task	▬	External Milestone	◆	Manual Summary Rollup	▬
Split	┈	Inactive Task	▭	Manual Summary	▬
Milestone	◆	Inactive Milestone	◇	Start-only	[
Summary	▬	Inactive Summary	▭	Finish-only	]
Project Summary	▬	Manual Task	▬	Deadline	⇩
External Tasks	▬	Duration-only	▬	Progress	▬

ID	ℹ	Task Mode	Task Name	Duration	Start	Finish			2008		
							Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr
86		📌	HVAC Rough-In	18 days	Mon 9/20/10	Wed 10/13/10					
87		📌	Imaging Equip Rough-In	20 days	Thu 10/7/10	Wed 11/3/10					
88		📌	X-Ray Equip Calibration	46 days	Thu 8/25/11	Thu 10/27/11					
89		📌	Ct Scan Equip Calibration	46 days	Thu 8/25/11	Thu 10/27/11					
90		📌	Punchlist	21 days	Fri 10/28/11	Fri 11/25/11					
91		⇨	**1st Floor Fitout Public Spaces & D**	**343 days**	**Mon 8/16/10**	**Thu 12/8/11**					
92		📌	Partition Layout	14 days	Mon 8/16/10	Thu 9/2/10					
93		📌	Ductwork Rough-In/testing	20 days	Thu 9/30/10	Wed 10/27/10					
94		📌	HVAC Equip/Accessories	25 days	Thu 10/7/10	Wed 11/10/10					
95		📌	Sprinkler Rough-In	25 days	Thu 10/7/10	Wed 11/10/10					
96		📌	HVAC Piping Rough-In/Testing	25 days	Thu 10/7/10	Wed 11/10/10					
97		📌	Plumbing Rough-In	15 days	Thu 10/7/10	Wed 10/27/10					
98		📌	Ductwork Rough-In	15 days	Thu 10/7/10	Wed 10/27/10					
99		📌	Rough-In Inspection	10 days	Thu 10/28/10	Wed 11/10/10					
100		📌	Punchlist	21 days	Wed 6/29/11	Wed 7/27/11					

Project: Project schedule.mpp
Date: Wed 10/27/10

Task	▬	External Milestone	◆	Manual Summary Rollup	▬
Split	┈	Inactive Task	▭	Manual Summary	▬
Milestone	◆	Inactive Milestone	◇	Start-only	[
Summary	▬	Inactive Summary	▭	Finish-only	]
Project Summary	▬	Manual Task	▬	Deadline	⬇
External Tasks	▬	Duration-only	▬	Progress	▬

ID	ℹ	Task Mode	Task Name	Duration	Start	Finish			2008		
							Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr
101			**1st Floor Fitout Connector**	**333 days**	**Mon 8/30/10**	**Thu 12/8/11**					
102			Demolition Red Bag Building	10 days	Wed 3/30/11	Tue 4/12/11					
103			Demolition Boiler Stack	25 days	Wed 3/30/11	Tue 5/3/11					
104			Earthwork/Bulk Excavation	10 days	Thu 5/5/11	Wed 5/18/11					
105			Remove Chillers	5 days	Thu 5/26/11	Wed 6/1/11					
106			Concrete Foundation/SOG	20 days	Fri 6/3/11	Thu 6/30/11					
107			Steel Erection	15 days	Fri 7/1/11	Thu 7/21/11					
108			Demolition Breakthrough	15 days	Mon 7/25/11	Fri 8/12/11					
109			Fireproofing	10 days	Mon 7/25/11	Fri 8/5/11					
110			Backfill	15 days	Mon 7/25/11	Fri 8/12/11					
111			Partition Layout	15 days	Mon 8/8/11	Fri 8/26/11					
112			Medical Gas Rough-In	15 days	Mon 8/15/11	Fri 9/2/11					
113			Plumbing	15 days	Mon 8/15/11	Fri 9/2/11					
114			Ductwork Rough-In	15 days	Mon 8/15/11	Fri 9/2/11					
115			Sprinkler Rough-in	15 days	Mon 8/15/11	Fri 9/2/11					

Project: Project schedule.mpp
Date: Wed 10/27/10

Task	▬	External Milestone	◆	Manual Summary Rollup	▬
Split	┈	Inactive Task	▭	Manual Summary	▬
Milestone	◆	Inactive Milestone	◇	Start-only	[
Summary	▬	Inactive Summary	▭	Finish-only	]
Project Summary	▬	Manual Task	▬	Deadline	⬇
External Tasks	▬	Duration-only	▬	Progress	▬

ID	ℹ	Task Mode	Task Name	Duration	Start	Finish
116		📌	Electrical Power/Lighting Rough-In	15 days	Mon 8/15/11	Fri 9/2/11
117		📌	Punchlist	10 days	Thu 11/10/11	Wed 11/23/11
118		⇨	**2nd Floor fitout C/D**	**333 days**	**Mon 8/30/10**	**Thu 12/8/11**
119		📌	Partiton Layout	17 days	Fri 10/8/10	Mon 11/1/10
120		📌	Ductwork ough-In/Testing	40 days	Thu 9/30/10	Wed 11/24/10
121		📌	Mech uip/Accessories	20 days	Thu 9/30/10	Wed 10/27/10
122		📌	HVAC uip/Accessories	20 days	Thu 9/30/10	Wed 10/27/10
123		📌	Electric Power/Lighting Rough-In	60 days	Thu 10/14/10	Wed 1/5/11
124		📌	Medical Gas Rough-In	20 days	Thu 10/21/10	Wed 11/17/10
125		📌	Sprinkler System Rough-In	35 days	Thu 11/4/10	Wed 12/22/10
126		📌	Punchlist	31 days	Thu 8/4/11	Thu 9/15/11
127		⇨	**3rd Floor Fitout C/D**	**333 days**	**Mon 8/30/10**	**Thu 12/8/11**

		2008		
Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qt

Project: Project schedule.mpp
Date: Wed 10/27/10

Task	▬	External Milestone	◆	Manual Summary Rollup	▬
Split	┈	Inactive Task	▭	Manual Summary	▬
Milestone	◆	Inactive Milestone	◇	Start-only	[
Summary	▬	Inactive Summary	▭	Finish-only	]
Project Summary	▬	Manual Task	▬	Deadline	⬇
External Tasks	▬	Duration-only	▬	Progress	▬

ID	ℹ	Task Mode	Task Name	Duration	Start	Finish	Qtr 3	Qtr 4	2008 Qtr 1	Qtr 2	Qtr
128		📌	Partiton Layout	22 days	Mon 8/30/10	Tue 9/28/10					
129		📌	Ductwork ugh-In/Testing	40 days	Thu 9/30/10	Wed 11/24/10					
130		📌	Mech p/Accessories	40 days	Thu 9/30/10	Wed 11/24/10					
131		📌	HVAC p/Accessories	40 days	Thu 9/30/10	Wed 11/24/10					
132		📌	Electric ower/Lighting Rough-In	40 days	Thu 9/30/10	Wed 11/24/10					
133		📌	Sprinkler System Rough-In	40 days	Thu 9/30/10	Wed 11/24/10					
134		📌	Punchlist	83 days	Tue 5/24/11	Thu 9/15/11					
135		📌	**4th Floor Fitout Elev Room**	**55 days**	**Fri 12/3/10**	**Thu 2/17/11**					
136		📌	ommissioning	61 days	Mon 9/12/11	Mon 12/5/11					
137		📌	Punchlist	61 days	Mon 9/12/11	Mon 12/5/11					
138		📌	Substantial Completion	0 days	Thu 12/8/11	Thu 12/8/11					

Project: Project schedule.mpp
Date: Wed 10/27/10

Task	▬	External Milestone	◆	Manual Summary Rollup	▬
Split	┅	Inactive Task	▭	Manual Summary	▬
Milestone	◆	Inactive Milestone	◇	Start-only	[
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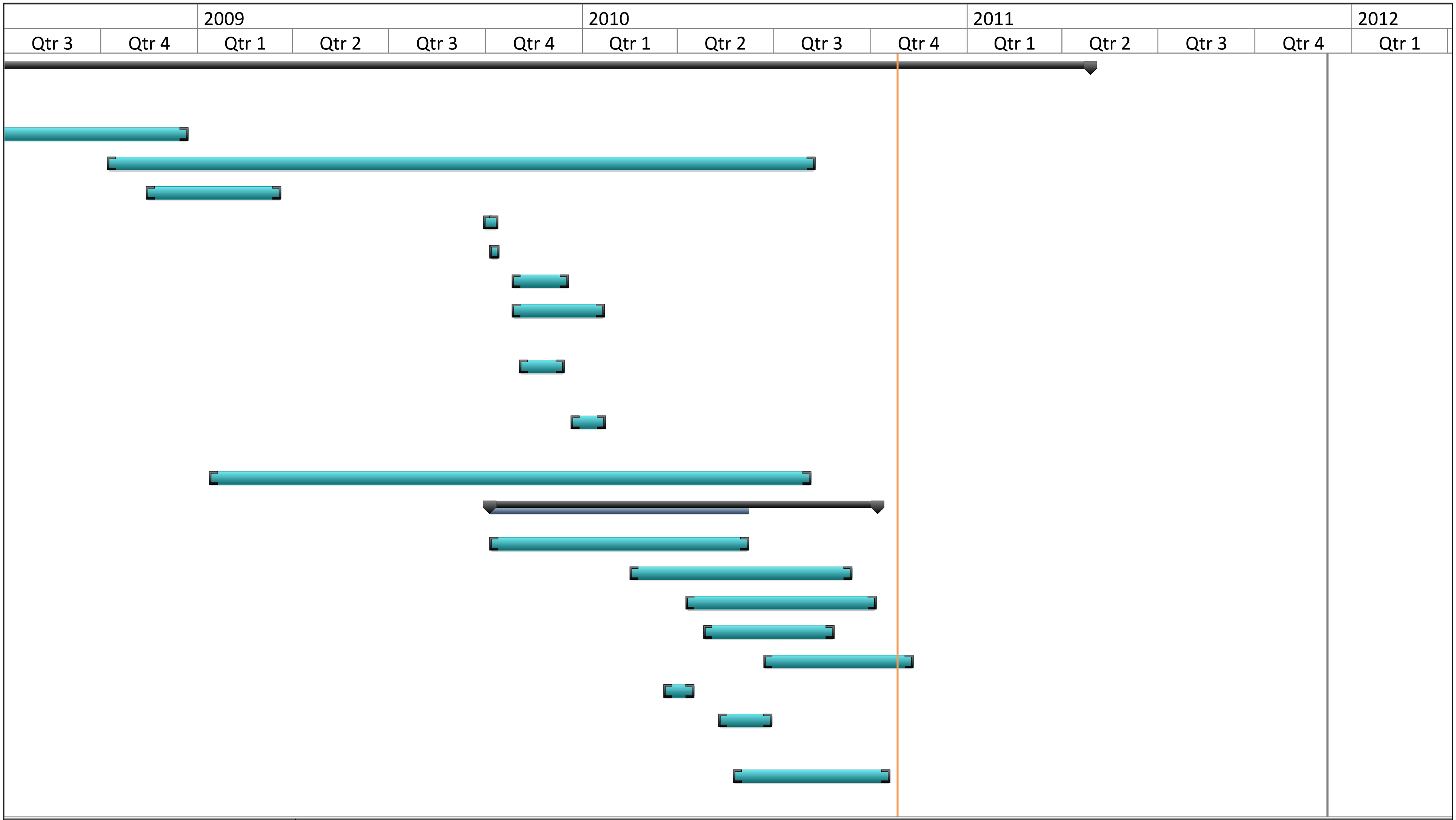
External Tasks	▬	Duration-only	▬	Progress	▬



Project: Project schedule.mpp
Date: Wed 10/27/10

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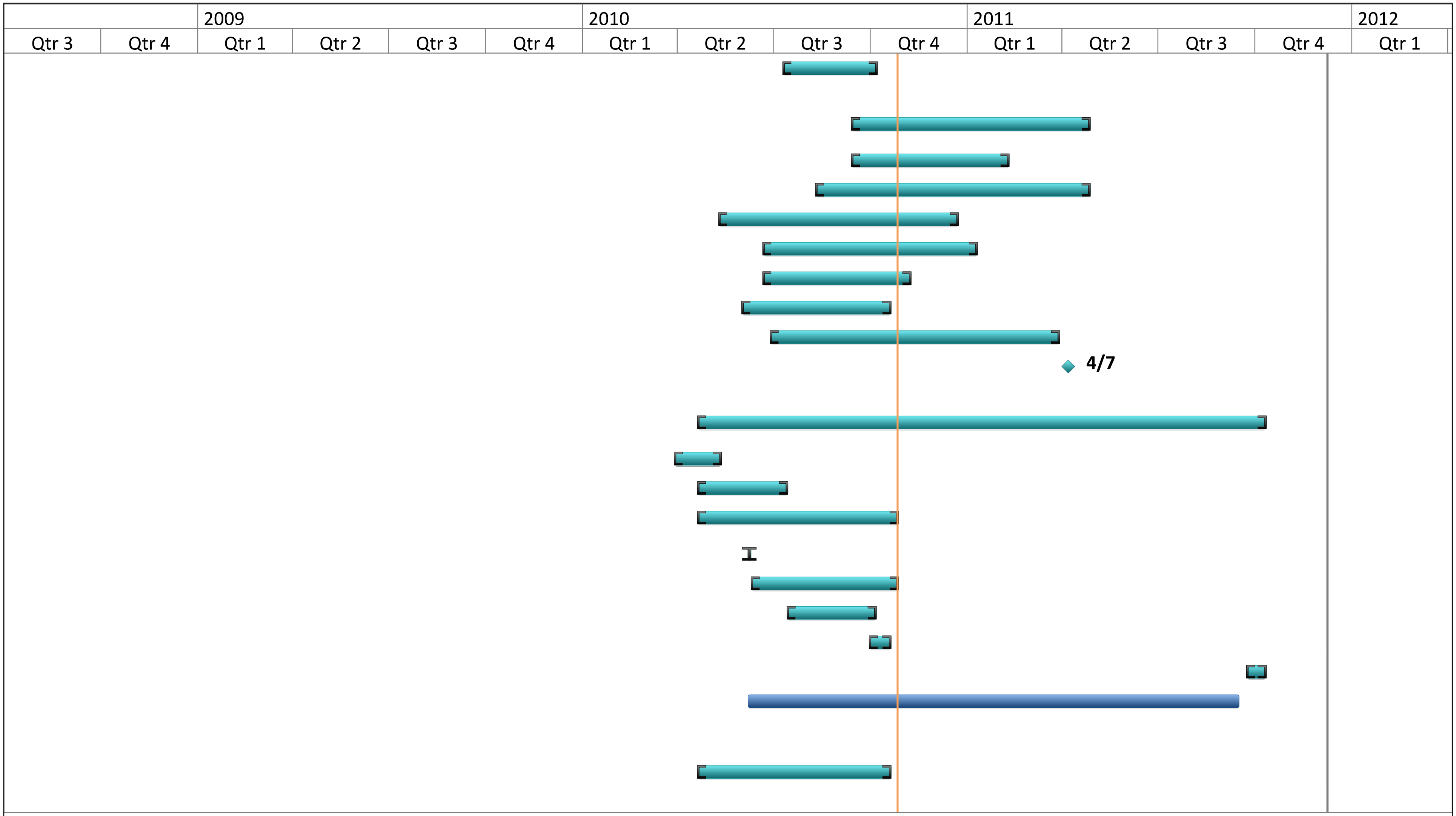
Split	┆	Inactive Task	▭	Manual Summary	▬
Milestone	◆	Inactive Milestone	◇	Start-only	[
Summary	▬	Inactive Summary	▭	Finish-only	]
Project Summary	▬	Manual Task	▬	Deadline	⬇
External Tasks	▬	Duration-only	▬	Progress	▬



Project: Project schedule.mpp
Date: Wed 10/27/10

Task	▬	External Milestone	◆	Manual Summary Rollup	▬
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Milestone	◆	Inactive Milestone	◇	Start-only	[
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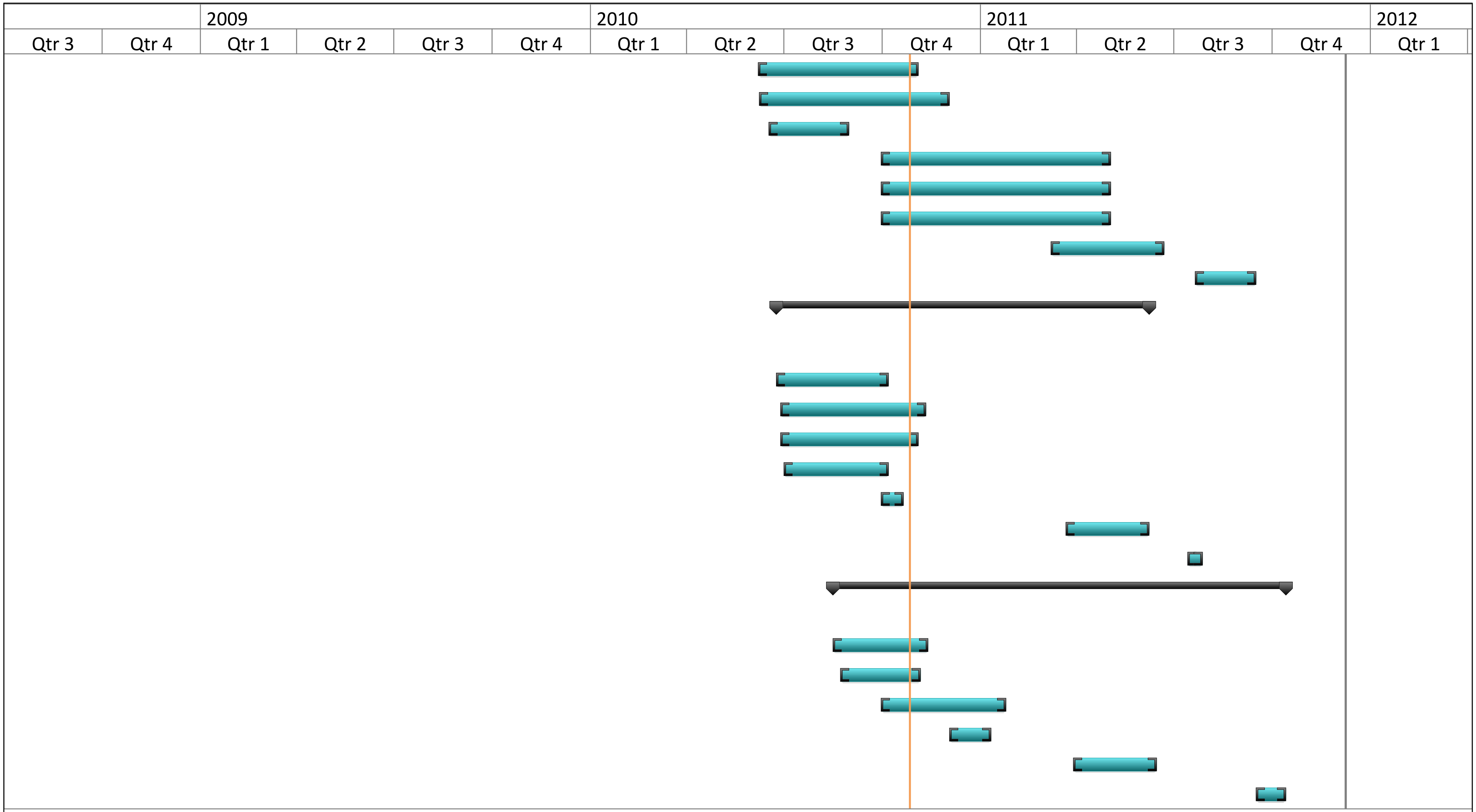
External Tasks	▬	Duration-only	▬	Progress	▬



Project: Project schedule.mpp
Date: Wed 10/27/10

Task	▬	External Milestone	◆	Manual Summary Rollup	▬
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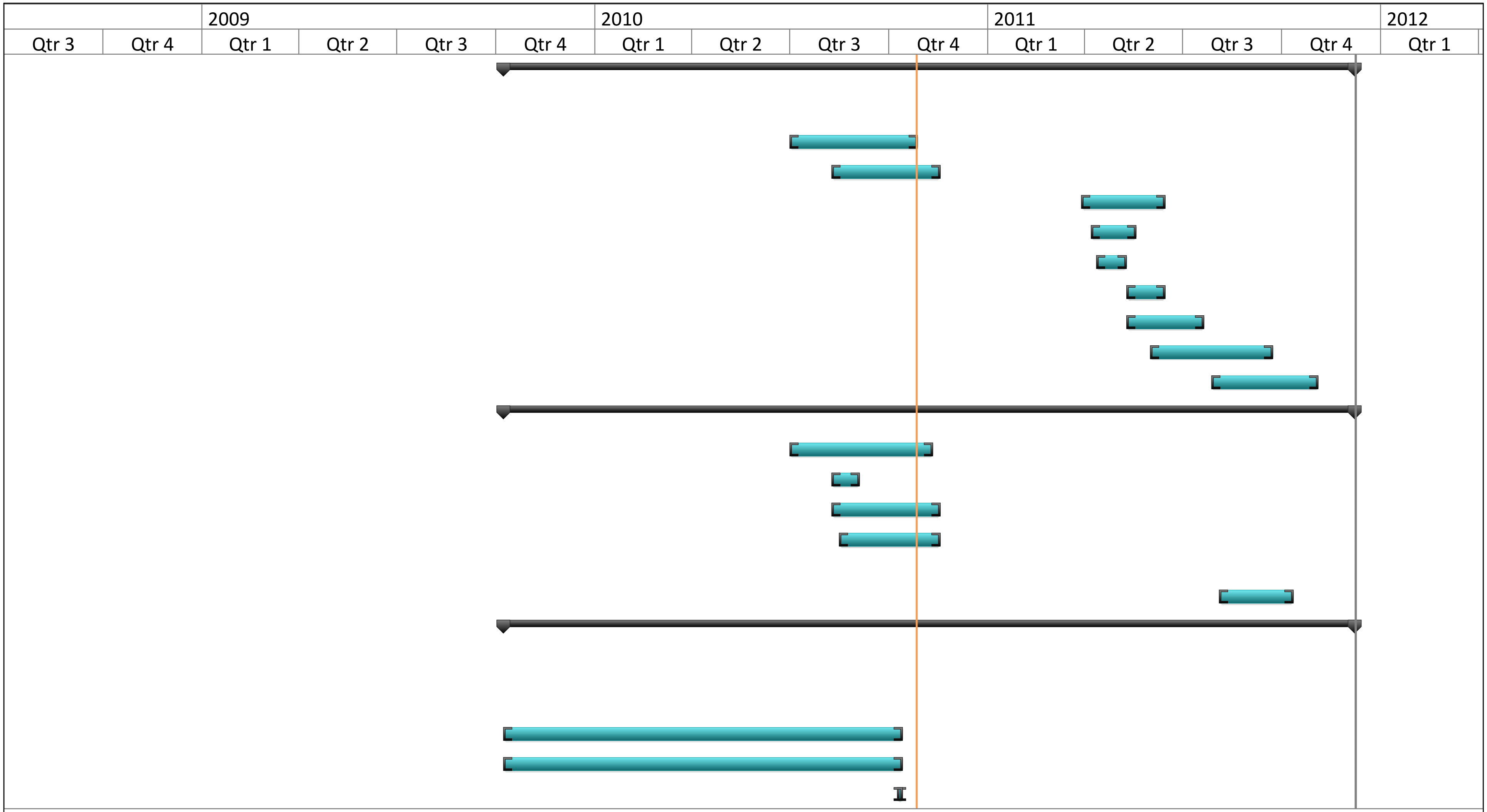
Milestone	◆	Inactive Milestone	◇	Start-only	⊏
Summary	▬	Inactive Summary	▭	Finish-only	⊐
Project Summary	▬	Manual Task	▬	Deadline	⬇
External Tasks	▬	Duration-only	▬	Progress	▬



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Date: Wed 10/27/10

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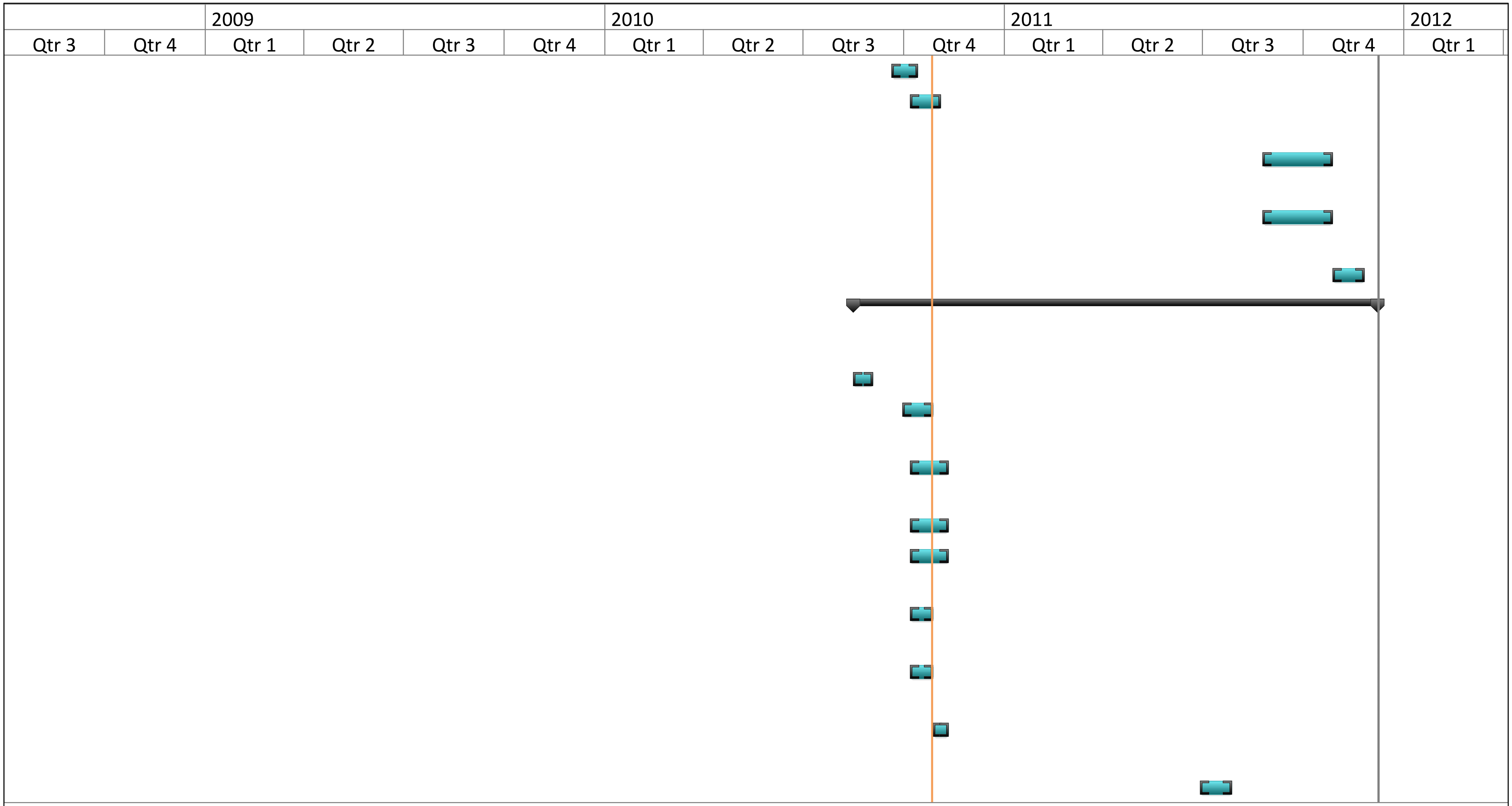
External Tasks	▬	Duration-only	▬	Progress	▬



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Milestone	◆	Inactive Milestone	◇	Start-only	[
Summary	▬	Inactive Summary	▭	Finish-only	]
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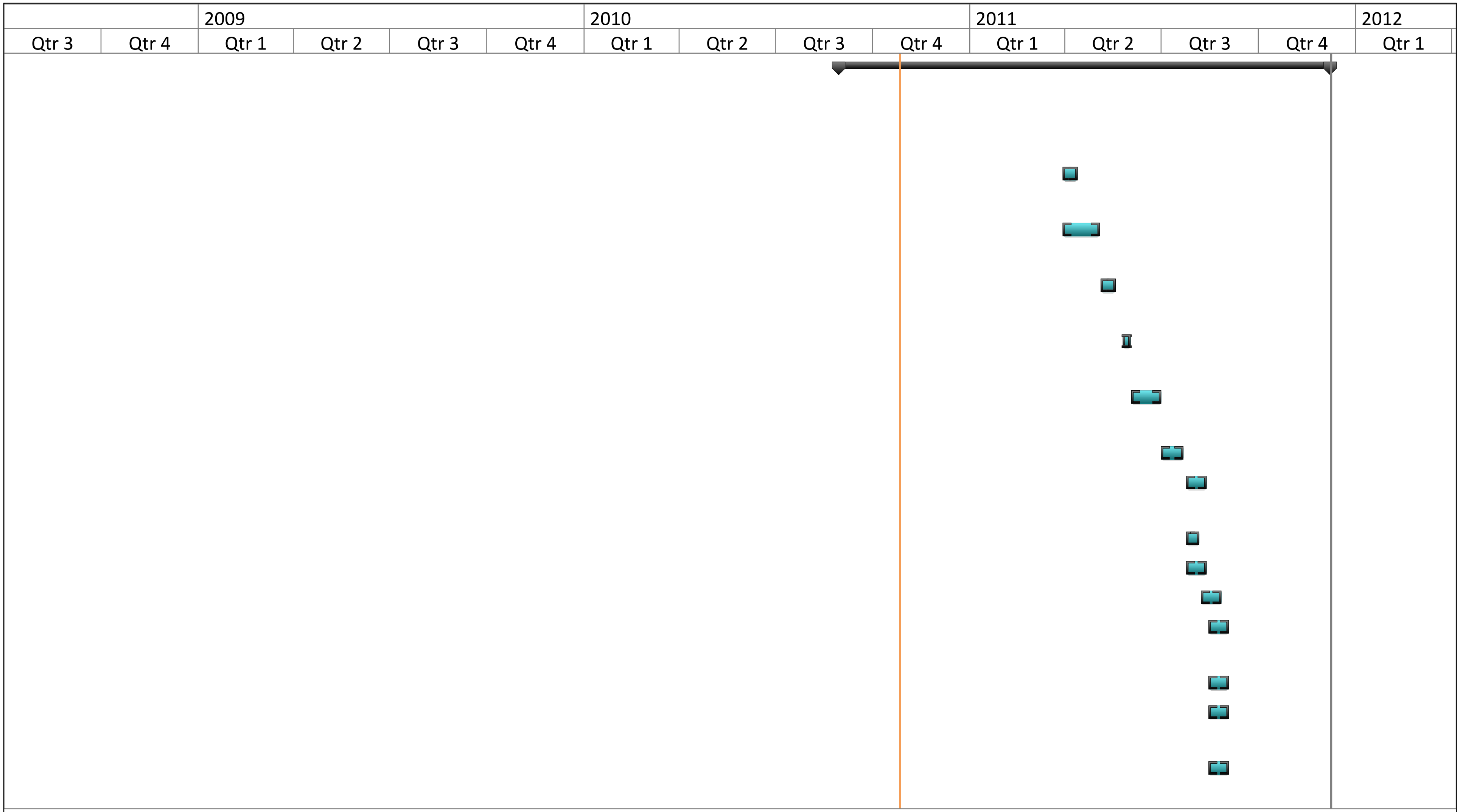
External Tasks	▬	Duration-only	▬	Progress	▬



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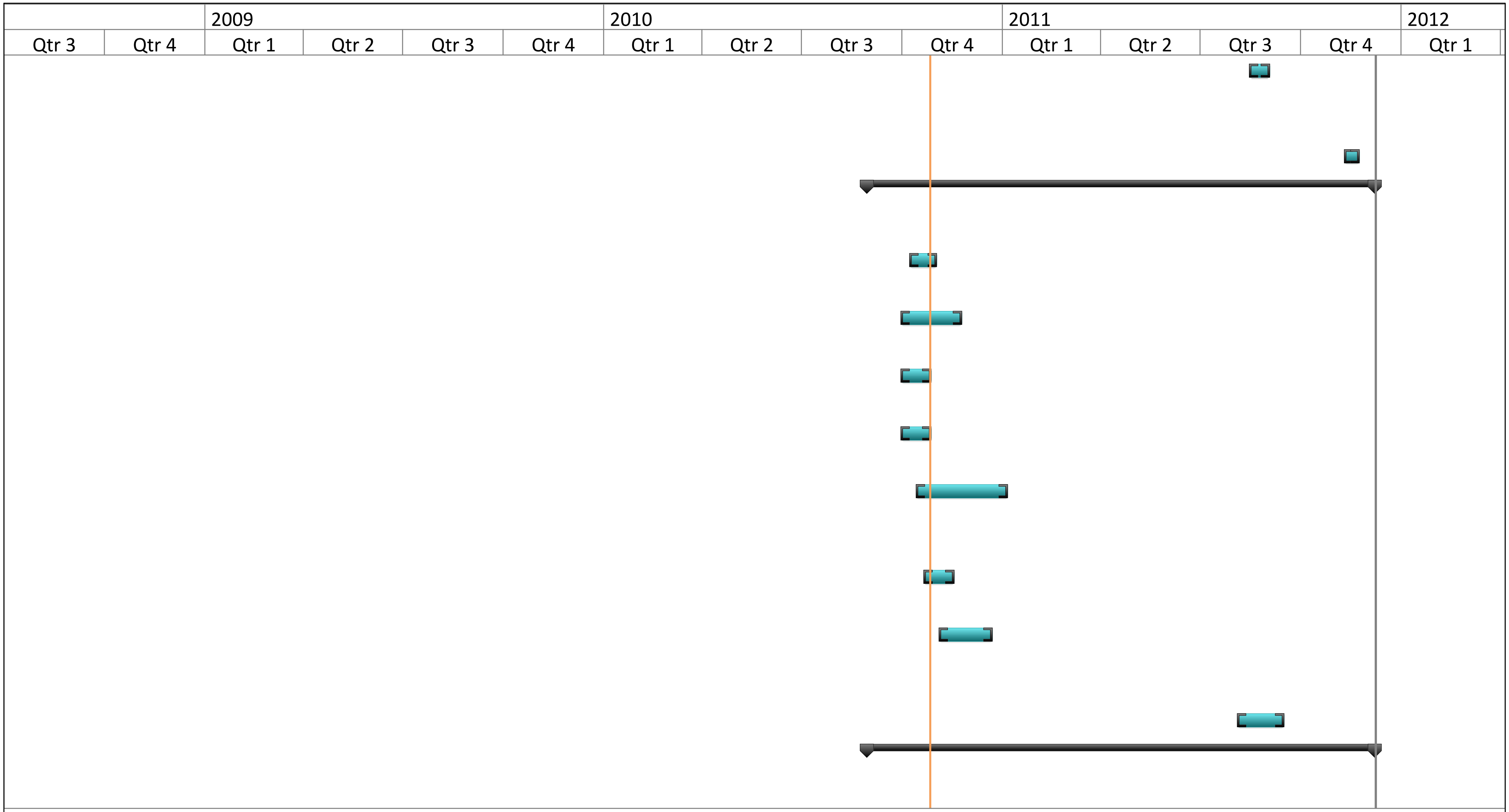
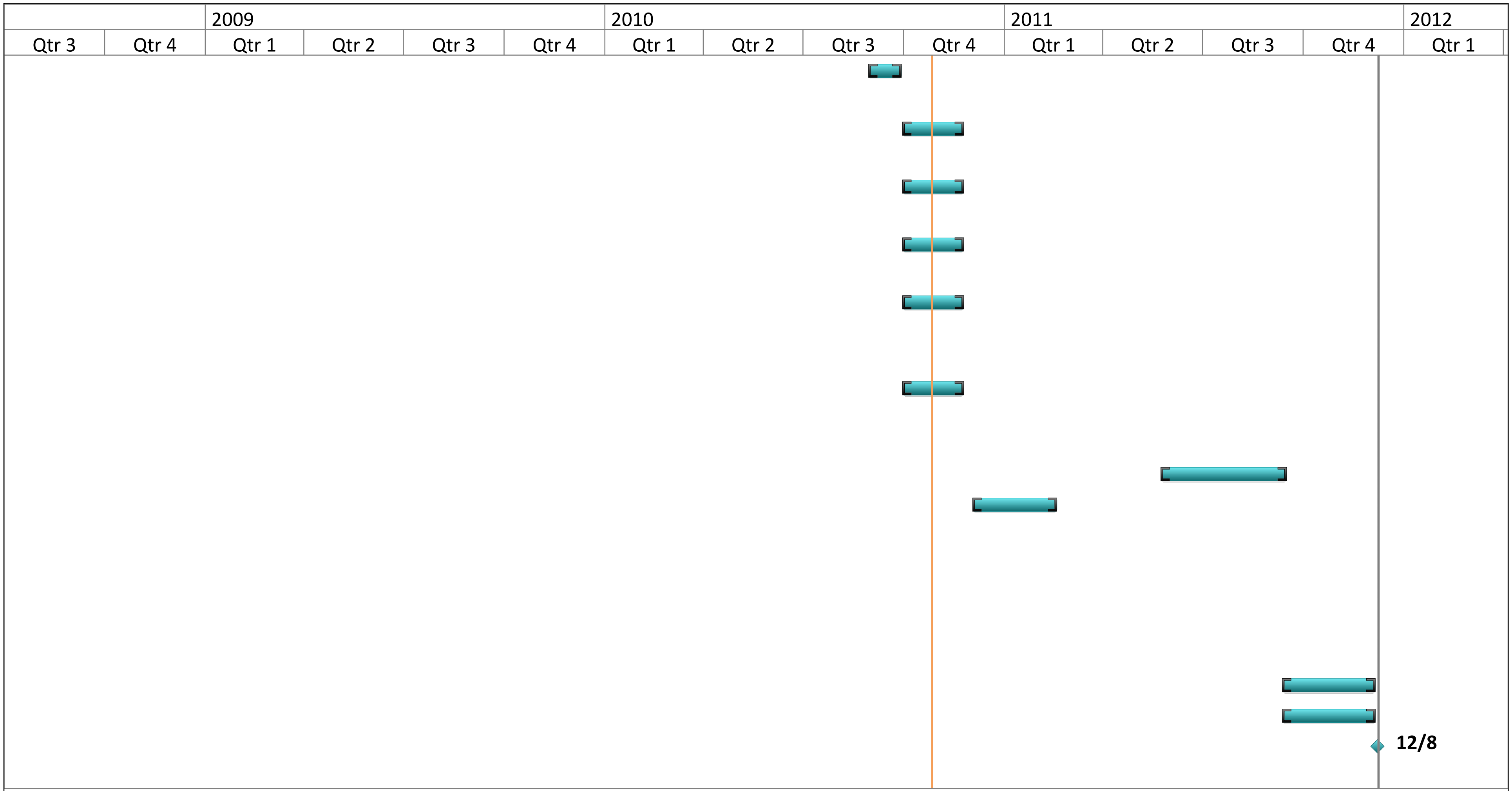
Task	▬	External Milestone	◆	Manual Summary Rollup	▬
Split	┈	Inactive Task	▭	Manual Summary	▬
Milestone	◆	Inactive Milestone	◇	Start-only	[
Summary	▬	Inactive Summary	▭	Finish-only	]
Project Summary	▬	Manual Task	▬	Deadline	⇩
External Tasks	▬	Duration-only	▬	Progress	▬



Project: Project schedule.mpp
Date: Wed 10/27/10

Task	▬	External Milestone	◆	Manual Summary Rollup	▬
Split	┈	Inactive Task	▭	Manual Summary	▬
Milestone	◆	Inactive Milestone	◇	Start-only	[
Summary	▬	Inactive Summary	▭	Finish-only	]
Project Summary	▬	Manual Task	▬	Deadline	⇩
External Tasks	▬	Duration-only	▬	Progress	▬



Project: Project schedule.mpp
Date: Wed 10/27/10

Task	▬	External Milestone	◆	Manual Summary Rollup	▬
Split	┈	Inactive Task	▭	Manual Summary	▬
Milestone	◆	Inactive Milestone	◇	Start-only	[
Summary	▬	Inactive Summary	▭	Finish-only	]
Project Summary	▬	Manual Task	▬	Deadline	⇩
External Tasks	▬	Duration-only	▬	Progress	▬

XIII. Appendix B: 7272 Specs

SECTION 07272

FLUID-APPLIED, VAPOR-PERMEABLE MEMBRANE AIR BARRIER
(AIR INFILTRATION BARRIER, AIB)

PART 1 GENERAL

1.01 SECTION INCLUDES

A. Fluid-applied, vapor-permeable membrane air barrier and accessory products.

B. Materials and installation methods for an air barrier assembly within exterior wall assemblies as indicated on drawings.

C. Materials and installation to bridge and seal the following air leakage pathways and gaps:

1. Connections of the walls to the roof air barrier
2. Connections of the walls to the foundations
3. Seismic and expansion joints
4. Openings and penetrations of window wall frames, door frames, store front, curtain wall and the like
5. Barrier envelope systems
6. Door frames, piping, conduit, duct and similar penetrations
7. Masonry ties, screws, bolts and similar penetrations
8. All other air leakage pathways through the exterior walls

1.02 RELATED SECTIONS

A. Section 03300 – Cast-In-Place Concrete

B. Section 04200 – Unit Masonry

C. Section 07132 – Waterproofing Membrane

D. Section 07212 – Rigid Insulation

E. Section 07264 – Spray Foam Sealant System

F. Section 07273 – Fluid Applied Membrane Air & Vapor Barrier

G. Section 07531 – Adhered Membrane Roofing

H. Section 07600 – Flashing and Sheet Metal

I. Section 08100 – Metal Doors and Frame

J. Section 08400 – Entrances and Storefronts

K. Section 08912 – Glazed Aluminum Curtain Walls

L. Section 08930 – Metal Stud Curtain Wall System

1.03 REFERENCES

A. ASTM C 920 Standard Specification for Elastomeric Joint Sealants.

B. ASTM C 1305 Standard Test Method for Crack Bridging Ability of Liquid-Applied Waterproofing Membrane.

C. ASTM D 412 Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers – Tension.

D. ASTM D 903 Standard Test Method for Peel and Stripping Strength of Adhesive Bonds.

E. ASTM D 1970 Standard Specification for Self-Adhering Polymer Modified Bituminous Sheet Materials Used as Steep Roofing Underlayment for Ice Dam Protection.

F. ASTM D 5590 Standard Test Method for Determining the Resistance of Paint Films and Related Coatings to Fungal Defacement by Accelerated Four-Week Agar Plate Assay.

G. ASTM E 96 Standard Test Methods for Water Vapor Transmission of Materials.

H. ASTM E 283 Standard Test Method for Determining the Rate of Air Leakage Through Exterior Windows, Curtain Walls and Doors under Specified Pressure Differences across the Specimen.

I. ASTM E 330 Standard Test Method for the Structural Performance of Exterior Windows, Doors, Skylights and Curtain Walls by Uniform Static Pressure Difference

J. ASTM E 331 Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure

K. ASTM E 783 Standard Test Method for Field Measurement of Air Leakage Through Installed Exterior Windows and Doors.

L. ASTM E 1105 Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform or Cyclic Static Air Pressure Difference.

M. ASTM E 2178 Standard Test Method for Air Permeance of Building Materials.

1.04 PERFORMANCE REQUIREMENTS

A. Installed Product and Accessories constitute an air barrier assembly, which shall be air-tight, durable and continuous, as described in Commonwealth of Massachusetts Building Code requirements: 780 CMR Chapter 13, Paragraphs 1304.3.1 Air Barriers and 1304.3.2 Air Barrier Penetrations.

B. Installed Product and Accessories shall exhibit no visible water leakage when tested per ASTM E 331 and shall perform as a liquid water drainage plane flashed to discharge to the exterior any incidental condensation or water penetration.

C. Installed Product and Accessories shall exhibit an air leakage rate not exceeding 0.004 CFM/ft^2 at 1.57 PSF according to ASTM E 283. Air leakage shall not exceed this rate while Product and Accessories remain soundly adhered after exposure to sustained and gust wind loading according to ASTM E 330.

D. Product, when applied at minimum 0.040 inch (40 mils) cured thickness, shall meet the following requirements:

REQUIREMENT	RESULT	TEST METHOD
Air Permeance	Not more than 0.0002 CFM/ft^2 @ 1.57 PSF	ASTM E 2178 modified, spray-applied over medium density concrete masonry unit (CMU) wall
Tensile Strength	Not less than 175 PSI	ASTM D 412
Tensile Elongation	Not less than 500 percent	ASTM D 412
Low Temperature Flexibility	No cracking at minus 5 degrees F	ASTM D 1970
Low-Temperature Crack Bridging	Pass at 0 degrees F	ASTM C 1305
Peel Adhesion on Concrete	Not less than 13 lb per inch of width	ASTM D 903
Peel Adhesion on Concrete Masonry Unit	Not less than 13 lb per inch of width	
Peel Adhesion on Exterior Grade Gypsum Sheathing	Substrate failure	
Water Vapor Permeance	Not less than 12 Perms	ASTM E 96, Method B
Mold Resistance	No growth	ASTM D 5590

1.05 SUBMITTALS

A. Provide submittals in accordance with Section 01300.

B. Shop drawings showing location and extent of air barrier and details of typical conditions.

C. Manufacturer's technical data sheets and material safety data sheets for Product and Accessories.

D. Manufacturer's installation instructions.

E. Manufacturer’s documentation of volatile organic compounds (VOC) content for Product and Accessories.

F. Certification of compatibility by Manufacturer, listing all materials on the project with which the Product and Accessories may come into contact.

G. Samples, 3 inch by 4 inch minimum size, of cured Product and Transition Membrane.

H. Provide material for building mock-up.

1.06 QUALITY ASSURANCE

A. Installer Qualifications: Installer shall be experienced in applying the same or similar materials and shall be specifically approved in writing by Manufacturer.

B. Single-Source Responsibility: Obtain Product and Accessories from single manufacturer for both AIB and AVB.

C. The VOC content shall be less than the current VOC content limits of South Coast Air Quality Management District (SCAQMD) Rule #1168 and all sealants used as fillers must meet or exceed the requirements of the Bay Area Quality Management District Regulation 8, rule 51.

D. Cooperate and coordinate with the Owner's inspection and testing agency. Do not cover any installed Product unless it has been inspected, tested and approved.

1.07 DELIVERY, STORAGE AND HANDLING

A. Deliver materials to Project site in original packages with seals unbroken, labeled with Manufacturer's name, product name, lot number and directions for storage.

B. Store materials in their original, undamaged packages in clean, dry, protected location and within temperature range required by Manufacturer.

C. Protect stored materials from direct sunlight. Protect Product from freezing. Do not store cylinders of Aerosol Contact Adhesive above 110 degrees F.

1.08 PROJECT CONDITIONS

A. Ambient temperature shall be above 40 degrees F during application and shall remain above 32 degrees F for 16 hours after application.

B. Do not apply during rain or if rain is expected within the next 16 hours.

C. Product applied by spray shall be maintained above 45 degrees F during application.

D. Do not spray in windy conditions. Protect surfaces from overspray.

E. Maintain cylinders of Aerosol Spray Contact Adhesive above 60 degrees F during spray.

F. Preinstallation Conference
   1. A minimum of two weeks in advance of installation of AIB, arrange a conference at the job site for the purpose of reviewing requirements and procedures for application of AIB and AVB; coordination of these activities; and satisfying any conditions which might interfere with proper application.
   2. Conference shall be attended by the Construction Manager, Contractor, Project Foreman for AIB and AVB Subcontractor, Subcontractors for adjacent substrates, the technical representative of AIB and AVB materials and the Architect.

1.09 WARRANTIES

A. Provide a full labor and materials for a minimum of five years, materials by the manufacturer, labor by the installer.

PART 2 PRODUCTS

2.01 PRODUCT

A. Basis of Design: Provide BarritechVP as manufactured by Carlisle Coatings & Waterproofing, Incorporated. 900 Hensley Lane, Wylie, TX 75098. Phone 1-800-527-7092. Website http://www.carlisle-ccw.com

B. Other Acceptable Manufacturers subject to compliance with requirements.
   1. Air Bloc 31 as manufactured by Henry.
   2. Perma Barrier VP as manufactured by Grace.

2.02 ACCESSORIES

A. Provide as manufactured by Carlisle Coatings and Waterproofing, Incorporated.
   1. Mesh Tape: AB-151 Scrim. 3-inch width, self-adhering fiberglass mesh tape.

B. Transition Membrane:
   1. CCW-705 Air & Vapor Barrier Strips
   2. CCW-705 LT Air & Vapor Barrier Strips

C. Contact Adhesive:
   1. Solvent-Based: CCW-702
   2. Water-Based: AWP
   3. Aerosol Spray: CAV-GRIP™

D. Mastic: LM 800 XL solvent-based synthetic rubber.

E. Transition to waterproofing shall be EPDM.

PART 3 EXECUTION

3.01 EXAMINATION

A. Examine substrates, areas, and conditions affecting installation of Product and Accessories for compliance with requirements. Verify that surfaces and conditions are suitable prior to commencing Work of this section. Do not proceed with installation until unsatisfactory conditions have been corrected.

B. Concrete shall be cured for a minimum of seven days.

C. Surfaces shall be sound, dry, and free of oil, grease, dirt, excess mortar or other contaminants.

D. Surfaces shall be supported and flush at joints without large voids or sharp protrusions.
   1. Damaged sheathing corners shall be soundly anchored and filled with material approved by Manufacturer.

E. Notify Architect in writing of:
   2. Cracks in concrete and masonry
   3. Gaps or obstructions such as steel beams, angles, plates and projections which cannot be spanned or covered by Product or Accessories.
   4. Anticipated problems applying Product and Accessories over substrate.

3.02 SURFACE PREPARATION

A. Fill rough gaps around pipe, conduit and similar penetrations with mortar, non-shrink grout or Polyurethane Foam. Allow cure of fill in rough gap. Apply a minimum ½ inch tooled bead of Joint Sealant or Mastic around pipe, duct and conduit type penetrations.

B. Treat sheathing joints with either method below:
   1. Center Mesh Tape over joint and adhere to surface. Lap adjacent pieces 1 inch minimum. Apply Product with putty knife into joint and over Mesh Tape.
   2. Fill with Joint Sealant and strike flush.

3.03 INSTALLATION

A. Allow materials used in Article 3.02 Surface Preparation to cure fully before applying Product.

B. Product application by spray:
   1. Dispense through spray equipment approved by Manufacturer.
   2. Spray even coverage on walls with overlapping passes at 0.060 inch (60 mils) minimum wet thickness.
   3. Apply full thickness in one application. If required thickness is not achieved in one coat, apply additional coat(s).

C. Product application by roller:

1. Dispense with medium to long nap roller.
2. Apply first coat at 0.030 inch (30 mils) minimum wet thickness.
3. Allow first coat to dry firm and apply second coat at 030 inch (30 mils) minimum wet thickness.

D. Apply over sheathing joint details.

E. Provide complete coverage without pinholes or voids. Apply greater thickness where necessary to provide continuous coating over rough surfaces and irregularities.

F. Allow Product to dry firm. Apply Transition Membrane over surface prepared with Contact Adhesive according to Manufacturer's instructions in the following areas:
   1. Openings for fenestration: Wrap opening. Extend into rough opening the full depth of fenestration and onto wall 3 inches minimum.
   2. Top of wall: Minimum 12 inch width
   3. Base of wall: Minimum 12 inch width, cover transition of base of wall to foundation. Extend minimum 8 inches onto wall.
   4. Transitions: Such as wall assembly junctions, columns and beams. Extend 3 inches minimum onto either side of transition
   5. Expansion and seismic joints exceeding 1 inch across: Cover with assembly consisting of minimum 12 inch width strip with 4 inch width strip centered along length and bonded to underside of wider strip.
   6. Expansion and seismic joints not more than 1 inch across: Extend 3 inches minimum onto either side of joint.

G. Lap adjacent pieces of Transition Membrane 2 inches minimum and sequence installation to provide shingled overlaps. Roll firmly to substrate with hand roller tool. Seal end laps, non-shingled laps, corner pinholes and terminating edges with Mastic. Install self-adhering flashing membrane to seal with stainless steel flashing and AIB in accordance with manufacturer's written instructions. The AIB shall lap over the self-adhering flashing membrane in a shingle fashion. The self-adhering flashing membrane shall lap over the stainless steel flashing in shingle fashion.

H. Transitioning to waterproofing shall be via EPDM, sealed and installed in shingle fashion as recommended by manufacturer to exclude all air/water.

3.04 SCHEDULE

A. Seal penetrations made through installed Product according to Article 3.02.

B. Fenestration installed after Product:
   1. Seal fenestration frame to Transition Membrane in rough opening with continuous Joint Sealant over backer rod or Polyurethane Foam.
   2. Seal mounting flange of doors and windows along jambs and head with minimum 4 inch width Transition Membrane strip. Apply Transition Membrane according to Article 3.03 Paragraph G.

C. Board insulation installed after Product: Attach with Aerosol Insulation Adhesive or with insulation adhesive by others which is acceptable with AIB manufacturer.

D. Roof air barrier: Join to Product according to Manufacturer's instructions and drawings.

3.05 REPAIR AND PROTECTION

A. Protect from damage during application and remainder of construction period.

B. Inspect before covering. Repair damage by removing loosely-adhered material and re-coating damage with Product according to Article 3.03 paragraph B or C. Repair shall extend beyond damage 2 inches minimum.

C. Product and Accessories are not designed for permanent exposure. Cover with exterior cladding as soon as schedule allows.

D. Outdoor exposure of installed Transition Membrane shall not exceed 60 days.

E. Outdoor exposure of installed Product shall not exceed 180 days.

++ END OF SECTION ++

XIV. Appendix C: 7273 Specs

SECTION 07273

FLUID-APPLIED MEMBRANE AIR & VAPOR BARRIER

(AIR AND VAPOR BARRIER, AVB)

PART 1 GENERAL

1.01 SECTION INCLUDES

A. Fluid-applied membrane air and vapor barrier and accessory products.

B. Materials and installation methods for an air and vapor barrier assembly within exterior wall assemblies as indicated on drawings.

C. Materials and installation to bridge and seal the following air leakage pathways and gaps:

1. Connections of the walls to the roof air barrier
2. Connections of the walls to the foundations
3. Seismic and expansion joints
4. Openings and penetrations of window wall frames, door frames, store front, curtain wall and the like
5. Barrier envelope systems
6. Door frames, piping, conduit, duct and similar penetrations
7. Masonry ties, screws, bolts and similar penetrations
8. All other air leakage pathways through the opaque walls

1.02 RELATED SECTIONS

A. Section 03300 – Cast-In-Place Concrete

B. Section 04200 – Unit Masonry

C. Section 07132 – Waterproofing Membrane

D. Section 07212 – Rigid Insulation

E. Section 07264 – Spray Foam Sealant System

F. Section 07272 – Fluid Applied Vapor Permeable Membrane Air Barrier

G. Section 07531 – Adhered Membrane Roofing

H. Section 07600 – Flashing and Sheet Metal

I. Section 08100 – Metal Doors and Frame

J. Section 08400 – Entrances and Storefronts

K. Section 08401 – Window Walls

L. Section 08912 – Glazed Aluminum Curtain Walls

M. Section 08930 – Metal Stud Curtain Wall System

1.03 REFERENCES

A. ASTM C 920 Standard Specification for Elastomeric Joint Sealants

B. ASTM C 1305 Standard Test Method for Crack Bridging Ability of Liquid-Applied Waterproofing Membrane

C. ASTM D 412 Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomer – Tension

D. ASTM D 903 Standard Test Method for Peel and Stripping Strength of Adhesive Bonds

E. ASTM D 1970 Standard Specification for Self-Adhering Polymer Modified Bituminous Sheet Materials Used as Steep Roofing Underlayment for Ice Dam Protection

F. ASTM D 5590 Standard Test Method for Determining the Resistance of Paint Films and Related Coatings to Fungal Defacement by Accelerated Four-Week Agar Plate Assay

G. ASTM E 96 Standard Test Methods for Water Vapor Transmission of Materials

H. ASTM E 283 Standard Test Method for Determining the Rate of Air Leakage Through Exterior Windows, Curtain Walls and Doors under Specified Pressure Differences across the Specimen

I. ASTM E 330 Standard Test Method for the Structural Performance of Exterior Windows, Doors, Skylights and Curtain Walls by Uniform Static Pressure Difference

J. ASTM E 331 Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure

K. ASTM E 783 Standard Test Method for Field Measurement of Air Leakage Through Installed Exterior Windows and Doors

L. ASTM E 1105 Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform or Cyclic Static Air Pressure Difference

M. ASTM E 2178 Standard Test Method for Air Permeance of Building Materials

1.04 PERFORMANCE REQUIREMENTS

A. Installed Product and Accessories constitute an air barrier assembly, which shall be air-tight, durable and continuous, as described in Commonwealth of

Massachusetts Building Code requirements: 780 CMR Chapter 13, Paragraphs 1304.3.1 Air Barriers and 1304.3.2 Air Barrier Penetrations.

B. Installed Product and Accessories shall exhibit no visible water leakage when tested per ASTM E 331 and shall perform as a liquid water drainage plane flashed to discharge to the exterior any incidental condensation or water penetration.

C. Installed Product and Accessories shall exhibit an air leakage rate not exceeding 0.02 L/s*m^2 at 75 Pa (0.004 CFM/ft^2 at 1.57 PSF) according to ASTM E 283. Air leakage shall not exceed this rate while Product and Accessories remain soundly adhered after exposure to sustained and gust wind loading according to ASTM E 330.

D. Installed Product and Accessories shall perform as a vapor barrier, installed on the predominantly warm side of the insulation.

E. Product, when applied at minimum 0.040 inch cured thickness, shall meet the following requirements:

REQUIREMENT	RESULT	TEST METHOD
Air Permeance	Not more than 0.~~0018~~**004** CFM/ft^2 @ 1.57 PSF	ASTM E 2178 modified, spray-applied over medium density concrete masonry unit (CMU) wall
Water Vapor Permeance	Not more than 0.02 Perm	ASTM E-96, Method B
Tensile Strength	Not less than 175 PSI	ASTM D 412
Tensile Elongation	Not less than 1000 percent	ASTM D 412
Low Temperature Flexibility	No cracking at minus 25 degrees F	ASTM D 1970
Low-Temperature Crack Bridging	Pass at 0 degrees F	ASTM C 1305
Peel Adhesion on HDPE Film	Not less than 25 lb per inch of width	ASTM D 903
Peel Adhesion on Concrete	Not less than 19 lb per inch of width	ASTM D 903
Peel Adhesion on Concrete Masonry Unit	Not less than 22.5 lb per inch of width	
Peel Adhesion on Exterior Grade Gypsum Sheathing	Substrate failure	

1.05 SUBMITTALS

A. Provide submittals in accordance with Section 01300

B. Shop drawings showing location and extent of air and vapor barrier and details of typical conditions

C. Manufacturer's technical data sheets and material safety data sheets for Product and Accessories

D. Manufacturer's installation instructions

E. Manufacturer's documentation of volatile organic compounds (VOC) content for Product and Accessories

F. Certification of compatibility by Manufacturer, listing all materials on the project with which the Product and Accessories may come into contact

G. Samples, 3 inch by 4 inch minimum size, of cured Product and Transition Membrane

H. Provide material for building mock-up

1.06 QUALITY ASSURANCE

A. Installer Qualifications: Installer shall be experienced in applying the same or similar materials and shall be specifically approved in writing by Manufacturer.

B. Single-Source Responsibility: Obtain Product and Accessories from single manufacturer for both AVB and AIB.

C. The VOC content shall be less than the current VOC content limits of South Coast Air Quality Management District (SCAQMD) Rule #1168 and all sealants used as fillers must meet or exceed the requirements of the Bay Area Quality Management District Regulation 8, rule 51.

D. Cooperate and coordinate with the Owner's inspection and testing agency. Do not cover any installed Product unless it has been inspected, tested and approved.

1.07 DELIVERY, STORAGE AND HANDLING

A. Preinstallation Conference
   1. A minimum of two weeks in advance of installation of AVB, arrange a conference at the job site for the purpose of reviewing requirements and procedures for application of AIB and AVB; coordination of these activities; and satisfying any conditions which might interfere with proper application.
   2. Conference shall be attended by the Construction Manager, Contractor, Project Foreman for AIB and AVB Subcontractor, Subcontractors for adjacent substrates, the technical representation of AIB and AVB materials and the Architect.

B. Deliver materials to Project site in original packages with seals unbroken, labeled with Manufacturer's name, product name, lot number and directions for storage.

C. Store materials in their original, undamaged packages in clean, dry, protected location and within temperature range required by Manufacturer.

D. Protect stored materials from direct sunlight. Protect Product from freezing. Do not store cylinders of Aerosol Contact Adhesive above 110 degrees F.

1.08 PROJECT CONDITIONS

A. Spray-Grade Product Application: Ambient temperature shall be above 20° F. Maintain product and the spray equipment above 50° F during application. Do not spray during rain, accumulating snow fall or in windy conditions. Protect surfaces from overspray.

B. Roller-Grade Product Application: Ambient temperature shall be above 40° F. Do not apply during rain, if rain is expected in the next 24 hours or if the temperature is expected to drop below 32° F in the next 24 hours.

C. Transition Membrane Application: Apply at ambient temperatures above 40° F unless procedure for low temperature application is followed. Do not apply during rain.

D. Low Temperature Application of Transition Membrane: Apply at ambient temperatures above 25° F. Do not apply during rain or accumulating snowfall. Store in heated area until use. Use transition membrane labeled LT, designating low-temperature formula.

E. Contact Adhesives: maintain cylinders of Aerosol Spray Contact Adhesive above 60° F during spray. Do not apply Water-Based Contact Adhesive at ambient temperatures below 40° F.

1.09 WARRANTIES

A. Provide a full labor and materials for a minimum of five years, materials by the manufacturers, labor by the installer.

PART 2 PRODUCTS

2.01 PRODUCT

A. Basis of Design: Barriseal-S (spray grade) pourable consistency, water based, polymer modified asphalt or Barriseal-R (roller grade) paste consistency, water based, polymer modified, asphalt as manufactured by Carlisle Coatings & Waterproofing, Incorporated.

B. Other Acceptable Manufacturers subject to compliance with requirements:
   1. Perm-A-Barrier as manufactured by W. R. Grace
   2. AirBloc 06 as manufactured by Henry

C. Transition to waterproofing shall be EPDM.

2.02 ACCESSORIES

A. Provide as manufactured by Carlisle Coatings and Waterproofing, Incorporated.
   1. Mesh Tape: CCW Barritape Scrim. 3-inch width, self-adhering fiberglass mesh tape.

B. Co-Spray: Barricure™ chloride-free liquid concentrate diluted with tap water at 3:1 ratio by volume.

C. Transition Membrane:
   2. CCW-705 Air & Vapor Barrier Strips
   2. CCW-705 LT Air & Vapor Barrier Strips

D. Sheathing Joint Treatment:
   3. 4 inch width Transition Membrane centered over joint and bonded to surface prepared with contact Adhesive
   2. Barritape™ centered over joint and bonded to surface prepared with Contact Adhesive.
   3. AB-151 Scrim centered over joint with Barriseal™-R covering scrim and filling joint.

E. Contact Adhesive:
   1. Solvent-Based: CCW-702
   2. Water-Based: AWP
   3. Aerosol Spray: CAV-GRIP™

F. Mastic:
   1. LC 800 XL solvent-based synthetic rubber.
   2. CCW-704 solvent-based rubber-modified asphalt.

G. Fill Compound
   1. Barriseal™-R Water-based, modified asphalt, 1-part
   2. CCW-703 V Modified polyurethane, 2-part
   3. LM 800 XL Solvent-based, synthetic rubber, 1-part
   4. CCW-201 Polyurethane, 2-part

H. Aerosol Insulation Adhesive
   1. Drain-Grip™ standard product
   2. CAV-GRIP™ low VOC product

I. Transition to waterproofing shall be EPDM.

2.03 RELATED MATERIALS BY OTHERS

A. Joint Sealant:
   1. CCW-201 Non-sag, 2-part polyurethane
   2. As approved by Manufacturer for compatibility with air & vapor barrier Products and Accessories. Shall conform to ASTM C 920 Type 1 or 2, Grade NS, Class 25 or 50.

B. Polyurethane Foam: Approved by Manufacturer for compatibility with air & vapor barrier Products and Accessories.

C. Insulation Adhesive: Approved by Manufacturer for compatibility with Products and Accessories.

PART 3 EXECUTION

3.01 EXAMINATION

A. Examine substrates, areas, and conditions affecting installation of Product and Accessories for compliance with requirements. Verify that surfaces and conditions are suitable prior to commencing Work of this section. Do not proceed with installation until unsatisfactory conditions have been corrected.

B. Concrete shall be cured for a minimum of seven days.

C. Surfaces shall be sound, dry, and free of oil, grease, dirt, excess mortar or other contaminants.

D. Surfaces shall be supported and flush at joints without large voids or sharp protrusions.

E. Damaged sheathing corners shall be soundly anchored and filled with material approved by Manufacturer.

F. Fill rough gaps around pipe, conduit and similar penetrations with mortar, non-shrink grout or Polyurethane Foam. Allow cure of fill in rough gap. Apply a minimum ½ inch tooled bead of Joint Sealant or Mastic around pipe, duct and conduit type penetrations.

G. Notify Architect in writing of:
    1. Cracks in concrete and masonry
    2. Gaps or obstructions such as steel beams, angles, plates and projections which cannot be spanned or covered by Product or Accessories.
    3. Anticipated problems applying Product and Accessories over substrate.

3.02 SURFACE PREPARATION

A. Treat sheathing joints:
    1. Center Mesh Tape over joint and adhere to surface. Lap adjacent pieces 1 inch minimum. Apply Product with putty knife into joint and over Mesh Tape.
    2. Fill with Joint Sealant using CCAW Barritape. Prime as required using one of the specified contact adhesives and strike flush.

B. Apply Transition Membrane over surface prepared with contact Adhesive according to Manufacturer's instructions in the following areas:
    3. Outside corners: minimum 6 inch width
    4. Openings for fenestration: Wrap opening. Extend into rough opening the full depth of fenestration and onto wall 3 inches minimum.
    3. Top of wall: Minimum 12 inch width.
    4. Base of wall: Minimum 12 inch width, cover transition of base of wall to foundation. Extend minimum 8 inches onto wall.
    5. Transitions: Such as wall assembly junctions, columns and beams. Extend 3 inches minimum onto either side of transition.
    6. Expansion and seismic joints exceeding 1 inch across: Cover with assembly consisting of minimum 12 inch width strip with 4 inch width strip centered along length and bonded to underside of wider strip.

7. Expansion and seismic joints not more than 1 inch across: Extend 3 inches minimum onto either side of joint.

C. Lap adjacent pieces of Transition Membrane 2 inches minimum and sequence installation to provide shingled overlaps. Roll firmly to substrate with hand roller tool. Seal end laps, non-shingled laps and corner pinholes with Mastic. Install self-adhering flashing membrane to seal with stainless steel flashing and AVB in accordance with manufacturer's written instructions. The AVB shall lap over the self-adhering flashing membrane in a shingle fashion. The self-adhering flashing membrane shall lap over the stainless steel flashing in shingle fashion.

3.03 INSTALLATION

A. Allow materials used in Article 3.02 Surface Preparation to cure fully before applying Product.

B. Product application by spray:
1. Dispense through spray equipment approved by Manufacturer.
2. Spray on walls working from bottom upward with overlapping passes. Keep spray streams perpendicular to wall.
3. Apply at 0.045 inch minimum wet thickness.
4. Apply full thickness in one application. If required thickness is not achieved in one coat, apply additional coat(s).

C. Product application by roller:
5. Dispense with medium to long nap roller.
2. Apply first coat at 0.030 inch minimum wet thickness.
3. Allow first coat to dry firm and apply second coat at 030 inch minimum wet thickness.

D. Apply over sheathing joint details.

E. Provide complete coverage without pinholes or voids. Apply greater thickness where necessary to provide continuous coating over rough surfaces and irregularities.

F. Allow Product to dry firm. Apply Transition Membrane over surface prepared with Contact Adhesive according to Manufacturer's instructions in the following areas:
6. Openings for fenestration: Wrap opening. Extend into rough opening the full depth of fenestration and onto wall 3 inches minimum.
2. Top of wall: Minimum 12 inch width
3. Base of wall: Minimum 12 inch width, cover transition of base of wall to foundation. Extend minimum 8 inches onto wall.
4. Transitions: Such as wall assembly junctions, columns and beams. Extend 3 inches minimum onto either side of transition
5. Expansion and seismic joints exceeding 1 inch across: Cover with assembly consisting of minimum 12 inch width strip with 4 inch width strip centered along length and bonded to underside of wider strip.
6. Expansion and seismic joints not more than 1 inch across: Extend 3 inches minimum onto either side of joint.

G. Lap adjacent pieces of Transition Membrane 2 inches minimum and sequence installation to provide shingled overlaps. Roll firmly to substrate with hand roller tool. Seal end laps, non-shingled laps, corner pinholes and terminating edges with Mastic.

H. Transitioning to waterproofing (Section 07132) shall be via EPDM, sealed and installed in shingle fashion as recommended by manufacturer to exclude all air/vapor/water.

3.04 SCHEDULE

A. Seal penetrations made through installed Product according to Article 3.02.

B. Fenestration installed after Product:
   1. Seal fenestration frame to Transition Membrane in rough opening with continuous Joint Sealant over backer rod or Polyurethane Foam.
   2. Seal mounting flange of doors and windows along jambs and head with minimum 4 inch width Transition Membrane strip. Apply Transition Membrane according to Article 3.03 Paragraph G.

C. Board insulation installed after Product: Attach with Aerosol Insulation Adhesive or with insulation adhesive by others which is acceptable with AVB manufacturer.

| D. ~~Roof air barrier~~**AIB/AVB Roof Transition**: Join to ~~Product~~ **roof product** according to Manufacturer's instructions and drawings.

3.05 REPAIR AND PROTECTION

A. Protect from damage during application and remainder of construction period.

B. Inspect before covering. Repair damage by removing loosely-adhered material and re-coating damage with Product according to Article 3.03 paragraph B or C. Repair shall extend beyond damage 2 inches minimum.

C. Product and Accessories are not designed for permanent exposure. Cover with exterior cladding as soon as schedule allows.

D. Outdoor exposure of installed Transition Membrane shall not exceed 60 days.

E. Outdoor exposure of installed Product shall not exceed 180 days.

+ + END OF SECTION + +

XV. Appendix D: Green Roof Specifications

GREENGRID®
The Natural Choice for Your Roof

The PREMIER Green Roof System

Specifications Summary

ELEMENT	DESCRIPTION
Module sizes *(nominal)*	**Ultra Extensive Modules** 2 ft. x 2 ft. x 2.5 in. deep (60.96 cm x 60.96 cm x 6.35 cm) **Standard Extensive Modules** 2 ft. x 2 ft. x 4in. deep (60.96 cm x 60.96 cm x 10.16 cm) 2 ft. x 4 ft. x 4 in. deep (60.96cm x 121.92 cm x 10.16 cm) 40 in. x 40 in. x 4 in. deep (101.6 cm x 101.6 cm x 10.16 cm) 2 ft. x 2 ft. x 2.8 ft. x 4 in. deep (60.96 cm x 60.96 cm x 85.3 cm x 10.16 cm) (triangle) ***NEW* GreenGrid® G3 Extensive Modules** 1.5 ft. x 2 ft. x 4in. (45.72 cm x 60.96 cm x 10.16 cm) **Intensive Modules** 2 ft. x 2 ft. x 8in. deep (60.96 cm x 60.96 cm x 20.32 cm) 2 ft. x 4 ft. x 8 in. deep (60.96 cm x 121.92 cm x 20.32 cm) 2 ft. x 2 ft. x 2.8 ft. x 8 in. deep (60.96 cm x 60.96 cm x 85.3 cm x 20.32 cm) (triangle)
Weight of planted modules	**Ultra Extensive Modules (2.5 in. depth)** – Approx. 11-13 lb. per ft^2 (53.7 – 63.5 kg/m^2) **Standard Extensive Modules (4 in. depth)** – Approx. 18-22 lb. per ft^2 (87.9 – 107.4 kg/m^2) ***New* GreenGrid® G3 Extensive Modules (4 in. depth)** – Approx. 21-25 lb. per ft^2 (102.5 – 122 kg/m^2) **Intensive Modules (8 in. depth)** – Approx. 36 - 44 lb. per ft^2 (175.7 – 214.7 kg/m^2) ** Weights based on bulk density at maximum water holding capacity. Weight may vary based on requirements for project-specific vegetation selections and variations in regional materials incorporated in growth media.*
Module material	100 % pre-consumer recycled high molecular weight polyethylene protected with UV inhibitor and stabilizers. – 150 mil. (Ultra Extensive & Extensive Modules) – 200 mil. (Intensive Modules)
Drainage clearance above roof	0.5 in. (1.27 cm)
Color of modules	Black
Filter fabric (if required)	Spunbonded polypropylene geotextile
Growth media	Proprietary engineered growth media blend of organic and inorganic components. Based upon German FLL standards.
Acceptable underlying materials	Waterproofing surface or any other roofing materials. Modules can be placed directly on membrane or other roof materials.
Vegetation	Perennials, grasses, or shrubs specifically selected for climate, hardiness zone, color, and size.

WESTON SOLUTIONS®

GREENGRID™
The Natural Choice for Your Roof

GreenGrid®
GREEN ROOF SYSTEM
GUIDE SPECIFICATIONS

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Vernon Hills, IL 60061
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SECTION 07710

GREENGRID® GREEN ROOF COMPONENTS

PART 1 - GENERAL

1.1 SCOPE

Furnish all labor, materials, tools, and equipment to unload, hoist and install GreenGrid® Green Roof System provided by Weston Solutions, Inc. (WESTON). The GreenGrid® System shall include modules, growth media and the vegetation as specified on drawings or as directed by the Project Engineer. This work shall also include installation of edge treatments, rubber pavers, decorative ballast, slip-sheet, and an irrigation system, if specified.

1.2 RELATED WORK SPECIFIED ELSEWHERE

A. Roofing Systems - specified in Section XXXX.

1.3 QUALITY ASSURANCE

A. There should be no deviation made from this specification or the detail drawings without prior written approval 14 days prior to the start of the project.

B. Before installation of the modules, the waterproofing surface shall be inspected by a technical representative of the waterproofing installer/manufacturer to determine the adequacy of the waterproofing surface to accept the modules.

C. It shall be the Owner's responsibility to determine the adequacy of the structure to support the existing and proposed loads. Verification of the integrity of the waterproofing for water tightness shall also be the responsibility of the Owner if the green roof is installed on an existing waterproofing system.

D. Upon completion of the installation, an inspection shall be conducted by a GreenGrid® Technical Representative to ascertain that the modules have been installed according to these specifications and details. This inspection is not intended to be a final inspection for the benefit of the owner but for the benefit of determining whether a warranty shall be issued.

E. The green roof modular components, growth media, vegetation, and other optional materials will be purchased from Weston Solutions, Inc., or through a licensed distributor.

1.4 SUBMITTALS

A. When the proposed project components vary outside of this specification, submit these altered components for review.

B. Submit an installation plan including but not limited to: waterproofing quality control, system delivery, and maintenance plan until green roof acceptance.

C. Provide a detailed water hook-up plan on the drawings if an irrigation system is required.

PART 2 - PRODUCTS

2.1 GREENGRID® MODULES

A. GreenGrid® Modules are formed of 150 mil (2.5-inch and 4-inch) and 200 mil (8-inch) recycled (100% pre-consumer) High Molecular Weight Polyethylene (HMWPE) protected with UV inhibitor and stabilizers.

B. GreenGrid® Modules sizes (Module OD = ± ⅛”):

1. Ultra-Extensive:
    a. 2’ x 2’x 2.5”
2. Extensive:

   a. Standard Modules
      2’ x 2’x 4”
      2’ x 4’x 4”
      40” x 40”x 4”
      2’ x 2’x 4” Triangle

   b. G3 Modules
      18” x 24”x4”

3. Intensive:

   a. 2’ x 2’x 8”

   b. 2’ x 4’x 8”

   c. 2’ x 2’x 8” Triangle

C. GreenGrid® Module to be delivered to the project location complete with growth media and pre-planted and/or pre-grown to a “percent” coverage with vegetation of the color and type desired by the client suitable for a green roof application.

D. GreenGrid® Module weights (Bulk density at maximum water holding capacity):

1. Ultra-Extensive System (2.5-inch): 11-13 lbs per sf

2. Extensive System (4-inch): 18-22 lbs per sf

3. Intensive System (8-inch): 35+ lbs per sf

E. GreenGrid® Module clearance above the roof is 0.5 inches.

2.2 GROWTH MEDIA

A. GreenGrid® Growth Media is an engineered light weight blend consisting of inorganic and organic components. Formulations are based on the

German FLL “Guidelines for Planning, Execution and Upkeep of Green-Roof Sites”

2.3 VEGETATION

A. GreenGrid® Modules are to be delivered to the project location complete with growth media and vegetation pre-planted and/or pre-grown to a “percent” coverage with plant species desired by the client suitable for green roof applications.

B. Extensive System – GreenGrid® recommended Extensive plant mixes are composed of highly drought resistant ground covers that can thrive in a non-irrigated (climate dependent), rooftop environment in the project location. Vegetation shall be selected according to their USDA hardiness zone classification.

1. Recommended planting density - Vegetation should be supplied in a minimum size of 2-inches deep by 1.5-inches wide (plugs) and planted 4 to 6 inches on center (18 to 16 plants per 2x4 module, respectively).

C. Intensive System – GreenGrid recommended Intensive plant mixes shall include grasses, perennials, and/or groundcovers that can thrive in an irrigated or non-irrigated, rooftop environment in the project location. Plants shall be selected according to their USDA hardiness zone classification.

1. Typical planting density - Vegetation should be supplied in grow-plug or quart size containers and planted in the GreenGrid® green roof modules at a rate of 8 to 12 inches on center (11 to 8 plants per 2x4 module, respectively).

D. Vegetation shall be installed in accordance with the landscape design

2.4 GREENGRID® ACCESORIES

A. Rubber Pavers (optional)

1. Standard Paver size: 2 feet by 2 feet, and 1.75-inches in depth. Various paver depths are available.

2. Pavers are composed of 100% recycled (post-consumer) rubber and are available in various colors.

3. Standard Paver weight: 7.5 lbs. per square foot.

B. Edge Treatments (optional)

Standard: 0.040 Painted Aluminum (recycled content 91%) or 24 gauge Painted Steel (recycled content 28 to 35%) for placement on viewable edge of modules.

C. Irrigation Systems (optional)

Irrigation requirements will be dependent upon project location and plant selection. For Extensive GreenGrid® Systems planted with a mix of highly drought resistant ground covers, an irrigation system is generally not needed (exceptions do apply to some arid climates). However, GreenGrid® strongly recommends a backup system to irrigate the green roof during prolonged droughts or during hot dry windy weather patterns. Simple overhead spray system with spray heads, or spigot/hose/sprinkler systems are inexpensive and effective methods. These also provide the means to optimize the evaporative cooling effect of the GreenGrid® Green Roof System during such weather events.

PART 3 - EXECUTION

3.1 DELIVERY AND HANDLING

A. Installation Season:

1. Northern Climates: Unless otherwise permitted, module installation

shall be done between April 15 and October 15, but not when the weather is below 50°F.

2. Southern Climates: Will be dependent upon weather and/or plant availability

B. Do not install on saturated roof surfaces or under freezing weather conditions, the latter unless with the express permission of Weston Solutions, Inc.

C. Coordinate the completion of installation within a 24-hour period from the time the modules are to be delivered.

D. Handle planted modules with care. Do not drop, kick, or point-load modules during handling and installation.

3.2 SITE PREPARATION

A. Perform module installation only after appropriate waterproofing system, with the proper taper to allow for drainage, has been installed and inspected. It is strongly recommended that these areas be leak tested prior to module installation to confirm water-tightness.

B. Erect safety signage and provide fall protection/fall prevention equipment as required under OSHA.

C. Restrict traffic from work areas until modules are installed and there after to restrict damage to the plant material.

D. Thoroughly sweep away all debris, foreign material, etc. from the waterproofing surface.

E. Refer to Waterproofing System manufactures’ recommendation toward acceptable slip-sheet protection fabric.

3.3 APPLICATION OF GREENGRID® MODULES

A. Remove all debris from the slip-sheet surface that might interfere with installation of the modules or compromising the integrity of the waterproofing surface.

B. Place modules over the slip-sheet in the desired locations in accordance with the landscape design.

C. Modules shall be installed in straight rows, tight against each other, and arranged in the proper directional orientation.

D. For connecting modules together, drill a hole through the middle of the outer lip at the top of the tray continuing through the inner wall of tray. Using a 150 pound black “zip tie,” put the tie through the hole and cinch up tight. The hole/zip tie shall be at 2 foot centers:

1. 2 x 2 modules - 4 ties per module

2. 2 x 4 modules - 6 ties per module

E. Installed modules shall be watered sufficiently with a fine spray so as to thoroughly moisten the growth media from top to bottom. Water shall be free of substances harmful to plant growth. Hoses or other methods of temporary irrigation shall be furnished by the Contractor.

3.4 WARRANTY

A. <u>GreenGrid® Modules:</u> WESTON warrants that each GreenGrid® Module (the “Product”) will perform its function of containing plant growth media for a period of twenty (20) years from the date of shipment of the Product by Weston. As used herein, “Product” means only the module and excludes (i) any plants, growth media, and any other materials placed within the GreenGrid modules, or (ii) any irrigation, mechanical, structural, or electrical components contained therein or attached thereto.

B. <u>Standard 30 Day Plant Limited Warranty</u>: WESTON will supply replacement plant(s) free of charge for any plant found to be dead or in severe decline (beyond the point of returning to aesthetic and economic value) for a period of 30 Days from the date of shipment of the Product by

Weston. This warranty only covers those species selected and/or approved selections by WESTON horticulturists. Those NOT approved but planted to meet a design requirement shall not be covered. This warranty is NOT in effect for plant material purchased and installed outside our recommended installation season (Installation Season: April 15th through October 15th) or plants purchased and installed by others.

C. OPTIONAL: 1 or 2 Year Extended Plant Limited Warranty. Please contact your local WESTON representative for details.

3.6 30-DAY MAINTENANCE PERIOD

A. Installation contractor shall maintain the GreenGrid® modules for a period of at least 30 days after completion prior to acceptance from building owner.

B. 30-Day maintenance shall include:

1. Water the GreenGrid® System once a week (weather dependent) too aid in plant establishment. System shall be watered more frequently during extended hot and dry weather especially when plants are showing signs of wilting.

2. Perform spot weeding as necessary.

3. Repair, rework, and replant all areas that have washed out or are eroded. Replace dead plants with new plants.

C. Upon completion of the 30-day maintenance period, a written maintenance plan for the specific green roof system shall be submitted to the building owner. A GreenGrid® Representative will be made available to go over this document.

3.7 ACCEPTANCE

A. Inspection to determine acceptance of modules will be made by the Owner, upon Contractor's request. Provide notification at least 7 working days before requested inspection date.

1. Modules will be acceptable, provided all requirements, including maintenance period, have been complied with, and healthy, even colored viable plants are established.

B. Upon acceptance, the Owner will assume module/plant maintenance.

3.8 CLEANING

A. Perform cleaning during installation of the work and upon completion of the work. Remove from site all excess materials, debris, and equipment.

END OF SECTION

XVI. Appendix E: TRACE Calculations

System Checksums

By ACADEMIC

System - 001 **VAV w/Baseboard Heating**

COOLING COIL PEAK / CLG SPACE PEAK

Cooling Coil Peak — Peaked at Time: Mo/Hr: 7 / 15; Outside Air: OADB/WB/HR: 90 / 75 / 106

Clg Space Peak — Mo/Hr: 7 / 18; OADB: 86

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	0	0	0	0	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	43,231	43,231	10	0	0
Glass Solar	0	0	0	0	0	0
Glass/Door Cond	0	0	0	0	0	0
Wall Cond	0	0	0	0	0	0
Partition/Door	0		0	0	0	0
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	0		0	0	0	0
Sub Total ==>	0	43,231	43,231	10	0	0
Internal Loads						
Lights	136,383	34,096	170,479	40	136,383	57
People	104,790	0	104,790	25	58,217	24
Misc	0	0	0	0	0	0
Sub Total ==>	241,174	34,096	275,270	65	194,600	82
Ceiling Load	36,572	-36,572	0	0	43,962	18
Ventilation Load	0	0	118,722	28	0	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	0		0	0	0	0
Exhaust Heat		-12,210	-12,210	-3		
Sup. Fan Heat			0	0		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	277,746	28,545	425,013	100.00	238,563	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design

OADB: 15

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	0	0.00
Roof Cond	0	-53,198	18.24
Glass Solar	0	0	0.00
Glass/Door Cond	0	0	0.00
Wall Cond	0	0	0.00
Partition/Door	0	0	0.00
Floor	0	0	0.00
Adjacent Floor	0	0	0
Infiltration	0	0	0.00
Sub Total ==>	0	-53,198	18.24
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	0	0	0.00
Sub Total ==>	0	0	0.00
Ceiling Load	-39,555	0	0.00
Ventilation Load	0	-200,798	68.84
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	0	0	0.00
Exhaust Heat		13,206	-4.53
OA Preheat Diff.		0	0.00
RA Preheat Diff.		-1,156	0.40
Additional Reheat		-49,736	17.05
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-39,555	-291,681	100.00

TEMPERATURES

	Cooling	Heating
SADB	58.3	72.0
Ra Plenum	81.5	68.3
Return	81.5	68.3
Ret/OA	84.0	16.7
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	10,890	3,267
Terminal	10,890	3,267
Main Fan	10,890	3,267
Sec Fan	0	0
Nom Vent	3,162	3,162
AHU Vent	3,162	3,162
Infil	0	0
MinStop/Rh	3,267	3,267
Return	10,890	3,267
Exhaust	3,162	3,162
Rm Exh	0	0
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	29.0	96.8
cfm/ft²	0.33	0.10
cfm/ton	307.46	
ft²/ton	940.21	
Btu/hr·ft²	12.76	-7.27
No. People	233	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB/WB/HR °F	Enter DB/WB/HR °F	Enter DB/WB/HR gr/lb	Leave DB/WB/HR °F	Leave DB/WB/HR °F	Leave DB/WB/HR gr/lb
Main Clg	35.4	425.0	302.0	10,552	84.0	68.9	82.2	58.3	56.6	65.9
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	35.4	425.0								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	33,300		
Part	0		
Int Door	0		
ExFlr	0		
Roof	33,300	0	0
Wall	0	0	0
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-89.3	0	0.0	0.0
Aux Htg	0.0	0	0.0	0.0
Preheat	-152.7	3,162	15.0	58.3
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-242.0			

Project Name:

Dataset Name: boomer.trc

TRACE® 700 v6.2.6.5 calculated at 05:26 PM on 03/16/2011

System Checksums

By ACADEMIC

System - 001 **VAV w/Baseboard Heating**

COOLING COIL PEAK / CLG SPACE PEAK

Cooling Coil Peak: Peaked at Time: Mo/Hr: 7 / 15; Outside Air: OADB/WB/HR: 90 / 75 / 106

Clg Space Peak: Mo/Hr: 7 / 18; OADB: 86

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	0	0	0	0	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	37,960	37,960	9	0	0
Glass Solar	0	0	0	0	0	0
Glass/Door Cond	0	0	0	0	0	0
Wall Cond	0	0	0	0	0	0
Partition/Door	0		0	0	0	0
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	0		0	0	0	0
Sub Total ==>	0	37,960	37,960	9	0	0
Internal Loads						
Lights	136,383	34,096	170,479	41	136,383	58
People	104,790	0	104,790	25	58,217	25
Misc	0	0	0	0	0	0
Sub Total ==>	241,174	34,096	275,270	65	194,600	83
Ceiling Load	34,313	-34,313	0	0	40,884	17
Ventilation Load	0	0	118,712	28	0	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	0		0	0	0	0
Exhaust Heat		-11,456	-11,456	-3		
Sup. Fan Heat			0	0		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	275,487	26,286	420,485	100.00	235,484	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design; OADB: 15

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	0	0.00
Roof Cond	0	-46,859	16.40
Glass Solar	0	0	0.00
Glass/Door Cond	0	0	0.00
Wall Cond	0	0	0.00
Partition/Door	0	0	0.00
Floor	0	0	0.00
Adjacent Floor	0	0	0
Infiltration	0	0	0.00
Sub Total ==>	0	-46,859	16.40
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	0	0	0.00
Sub Total ==>	0	0	0.00
Ceiling Load	-34,986	0	0.00
Ventilation Load	0	-200,798	70.27
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	0	0	0.00
Exhaust Heat		11,681	-4.09
OA Preheat Diff.		0	0.00
RA Preheat Diff.		-606	0.21
Additional Reheat		-49,162	17.21
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-34,986	-285,744	100.00

TEMPERATURES

	Cooling	Heating
SADB	58.3	72.0
Ra Plenum	81.3	68.7
Return	81.3	68.7
Ret/OA	83.9	15.9
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	10,715	3,215
Terminal	10,715	3,215
Main Fan	10,715	3,215
Sec Fan	0	0
Nom Vent	3,162	3,162
AHU Vent	3,162	3,162
Infil	0	0
MinStop/Rh	3,215	3,215
Return	10,715	3,215
Exhaust	3,162	3,162
Rm Exh	0	0
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	29.5	98.4
cfm/ft²	0.32	0.10
cfm/ton	305.78	
ft²/ton	950.33	
Btu/hr·ft²	12.63	-7.10
No. People	233	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB/WB/HR °F	Enter DB/WB/HR °F	Enter DB/WB/HR gr/lb	Leave DB/WB/HR °F	Leave DB/WB/HR °F	Leave DB/WB/HR gr/lb
Main Clg	35.0	420.5	297.5	10,416	83.9	68.9	82.4	58.3	56.6	65.8
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	35.0	420.5								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	33,300		
Part	0		
Int Door	0		
ExFlr	0		
Roof	33,300	0	0
Wall	0	0	0
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-84.2	0	0.0	0.0
Aux Htg	0.0	0	0.0	0.0
Preheat	-152.4	3,162	15.0	58.3
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-236.6			

XVII. Appendix F: 3-D Coordination Case Study

3D AND 4D MODELING FOR DESIGN AND CONSTRUCTION COORDINATION: ISSUES AND LESSONS LEARNED

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SUMMARY: *3D and 4D modeling tools have been available in the marketplace for some time. The past few years has seen a growing interest from the design and construction community to adopt these tools. As many project teams are realizing, implementing 3D and 4D modeling on an actual project is a complicated process that requires a coordinated effort. No guidelines currently exist on using these tools in a multi-disciplinary and multi-organizational environment and project teams are forced to figure this out on their own in real time as the project progresses. This paper addresses this shortcoming by providing guidelines that describe how to overcome the technical, procedural and organizational issues confronted by project teams as they undertake this new way of working. Specifically, the paper describes different approaches for assembling a project team to leverage these technologies, the modeling requirements for implementing 3D and 4D projects, the 3D and 4D modeling processes, the benefits and shortcomings of the process and technologies, the effect of these technologies on the project's outcome, and the lessons learned. This paper is intended for industry professionals interested in pursuing this type of innovative project delivery. This paper will also be of interest to researchers as it illustrates the limitations of emerging 3D and 4D technologies.*

KEYWORDS: *3D model, 4D model, computer aided design (CAD), virtual design and construction, virtual building technologies, design coordination, MEP coordination, construction scheduling.*

1. INTRODUCTION

In recent years, we have seen significant improvements in the tools available to model a construction project using 3D and 4D technologies. Current 3D modeling tools offer pre-defined objects that facilitate the development, routing, and connection of building systems in 3D, and provide conflict detection mechanisms that help to automatically identify physical interferences between components. 4D modeling tools link a project's scope in 3D with the construction schedule to graphically simulate the construction process. Many research efforts have discussed the potential of these tools to significantly improve design coordination and construction execution. However, implementing 3D and 4D modeling on an actual project in a multi-disciplinary and multi-organizational environment is a complicated process that requires a coordinated effort. There are a variety of technical, procedural, and organizational issues that must be addressed, which might explain their limited use. Moreover, there is little research that critiques these tools in the context of project teamwork on actual projects. Yet, without demonstrating their benefits and providing guidelines for implementation, it is difficult for practitioners to invest the resources necessary to adopt these technologies.

In practice, 3D and 4D technologies have been applied on a variety of construction projects. Prior research efforts have compiled detailed case studies that assess the benefits and limitations of these tools and their impact on project performance (Fischer and Haymaker 2001, Staub-French and Fisher 2001, Kam et al., 2003). Researchers have also critiqued the functionality of 3D and 4D technologies to meet the needs of industry (McKinney and Fischer 1998, Songer et al, 1998, Koo and Fischer 2000, Heesom and Mahdjuobi 2004). Some research efforts have also investigated the application of 3D and 4D modeling tools for specific purposes, such as constructability analysis (Ganah et al. 2005) and resource management (e.g., Akinci et al. 2003). Other research studies have documented the benefits and challenges of applying 3D / 4D tools specifically to the coordination of Mechanical, Electrical, Plumbing, and Fire Protection (MEP/FP) systems on complex projects (e.g., Khanzode et al., 2005, Staub-French and Fischer 2001). Finally, researchers have also investigated techniques to enhance the interaction capabilities of 3D and 4D models using immersive technologies (Messner et al. 2006) and virtual reality (Whyte et al. 2000). These studies clearly demonstrate that 3D/4D technologies have been well established and can be applied to resolve complex design and construction challenges. Although much has been written on the application of 3D and 4D technologies, few guidelines exist that outline what is required for multi-disciplinary project teams to apply these tools in real time on actual construction projects.

This paper provides 3D and 4D modeling guidelines for industry professionals interested in pursuing this type of innovative project delivery. These guidelines generalize the authors' unique experience as model developers, integrators, and coordinators on two different building construction projects, and outline an optimized process for implementation based on their lessons learned. We discuss the technical, procedural and organizational issues confronted by project teams as they undertake this new way of working. Specifically, the paper describes different approaches for assembling a project team to leverage these technologies, the modeling requirements for implementing 3D and 4D projects, the 3D and 4D modeling processes, the benefits and shortcomings of the process and technologies, the effect of these technologies on the project's outcome, and the lessons learned. This paper is intended for industry professionals interested in implementing these technologies on actual projects. This paper will also be of interest to researchers as it illustrates the limitations of emerging 3D and 4D technologies and the challenges of using them in practice.

The projects studied demonstrate that although there is room for improvement, current 3D and 4D technologies provide significant benefits to project teams in developing coordinated and constructible designs and construction sequences. Specifically, 3D and 4D models help project teams to identify design conflicts, design errors, sequencing constraints, access issues, fabrication details, and procurement constraints that impact the efficiency of the project delivery process. We believe that the use of these tools help project teams minimize risk and attract quality team members to construction projects and will be commonplace in the coming years as the industry copes with the realities of a tight labor market. We found that these technologies had a dramatic impact on project execution, including:

- the elimination of field interferences,
- less rework,
- increased productivity,
- fewer requests for information,
- fewer change orders,
- less cost growth, and
- a decrease in time from start of construction to facility turnover.

The next sections describe the scope and organization of the projects studied, the 3D and 4D coordination processes, and the impact of 3D and 4D technologies on the project's outcome.

2. PROJECT SCOPE AND ORGANIZATION

The authors worked on two different building construction projects that implemented 3D and 4D modeling to various degrees throughout the design and construction process: (1) Camino Medical Center in Mountain View, California; and (2) Sequus Pharmacueticals Pilot Plant Facility in Menlo Park, California. The next sections describe these projects in detail, including the scope, the organization, the modeling responsibilities, and the authors' roles on the project.

2.1 The Camino Medical Group Project

The Camino Medical Group project in Mountain View California is a new Medical Office Building facility. The project scope includes a 250,000 square foot, three-storey Medical Office Building and a two-storey 1,400 space parking garage. The Medial Office Building includes patient exam rooms, doctor's offices, surgery and radiology rooms, public spaces, a cafeteria, numerous conference rooms etc. The project owner, Sutter Health, a major provider of Healthcare services in Northern California, adopted Virtual Building technologies (specifically 3D / 4D tools) for the successful delivery of this project. The negotiated contract for this project is about $100M. Construction started in January 2005 and the project was completed on April 30th, 2007.

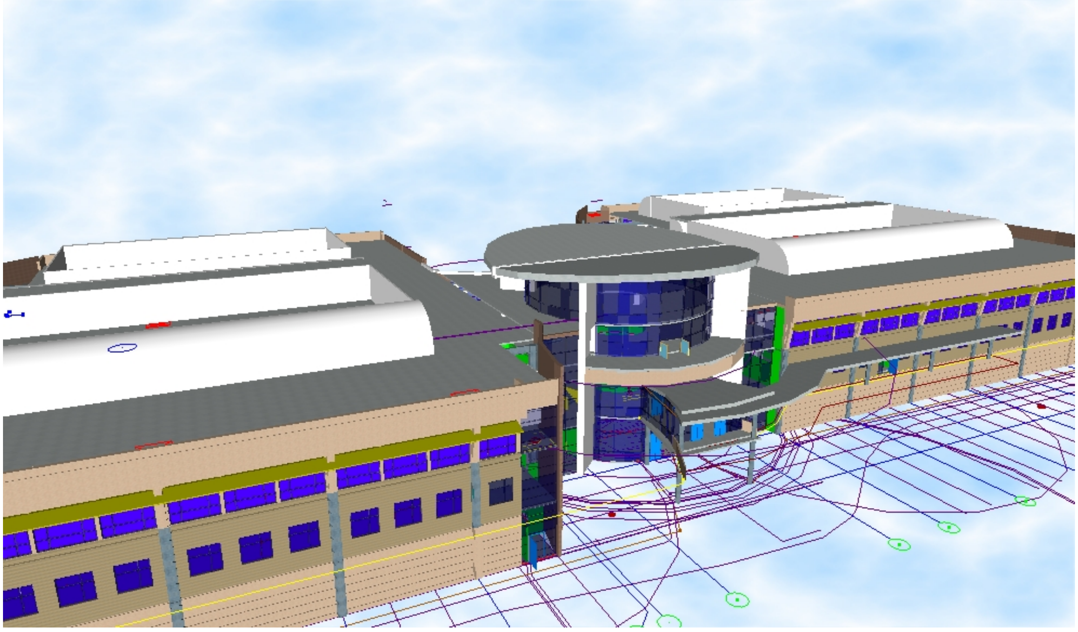


FIG. 1: 3D rendering of the three-storey medical office building for the Camino Medical Group Project in Mountain View, California.

2.1.1 Project Organization

The Architect for this project is Hawley Peterson and Snyder Architecture, the Mechanical Engineer is Capital Engineering, and the General Contractor is DPR Construction Inc. The owner, along with the Architect, Engineers and Contractor pre-qualified the MEP and FP subcontractors for their ability to work using the 3D / 4D coordination and collaboration tools. A detailed guideline was created to pre-qualify the subcontractors for their ability to collaborate using 3D / 4D tools. This guideline included the ability to produce 3D models using parametric objects, and compatibility of software products with the design review software. The MEP/FP subcontractors selected for this project include Southland Industries (HVAC), JW McClenahan Company (Plumbing), Cupertino Electric (Electrical) and North Star Fire Protection (Fire Protection).

2.1.2 Modeling Responsibilities

The Architect was responsible for providing the 3D model for the architectural and structural scope of work. The subcontractor team used these architectural and structural models to model their scope of work. The General Contractor was responsible for coordinating the MEP Design process, which included performing clash detection and resolution using the 3D models, coordinating the installation sequence for the MEP trades, and producing 4D models. The subcontractors agreed to develop their design using 3D tools under a Design-Assist method and agreed to complete coordination using 3D / 4D tools.

The MEP Design on this project is unique in the sense that it is being managed using the Lean Project delivery process. It is not the intent of this paper to explain Lean Construction. For more information, refer to the Lean Construction Institute website (www.leanconstruction.org). In essence, Lean Construction advocates early involvement of subcontractors in the design process, the elimination of negative iteration, and pulling the design from the construction sequence. On the Camino Project, the MEP subcontractors were brought on board in the Schematic Design phase. They were responsible for assisting the engineers in the Detailed Design phase and producing a fully coordinated set of 3D MEP models in the Construction Documents phase. Table 1 shows the modeling responsibilities for the Camino project and the project phase that the model was created. The starting point for the coordination process was the Architectural and Structural 3D model that was created in the Schematic Design stage. The subcontractors then took these models and developed the 3D models on their own in the Design Development stage. The objective of the program was to eliminate negative iteration and reduce the cycle time by using the 3D models created by the subcontractors to develop a fully coordinated MEP / FP model that could be used for fabrication and construction.

TABLE 1: Modeling Responsibilities for the Camino Medical Group Project.

Company	**Role**	**Modeling Scope**	**3D Software**	**Phase Model Created/Coordinated**
Hawley Peterson and Snyder	Architect	Architectural Modeling in 3D	Autodesk Architectural Desktop (ADT)	Schematic Design
KPFF Engineers	Structural Engineers	Structural Steel, Concrete Foundation, and Shear Walls in 3D	ADT, ETABS	Schematic Design
Capital Engineering	Mechanical Engineers	Mechanical Systems in 2D	AutoCAD	Schematic Design
The Engineering Enterprise	Electrical Engineers	Electrical Systems in 2D	AutoCAD	Schematic Design
DPR Construction, Inc.	General Contractor	Overall Coordination of MEP in 3D	NavisWorks, ADT	Design Development
Southland Industries	Mechanical Subcontractor	Ductwork and Piping in 3D	3D Pipe Designer, CADDuct, NavisWorks	Design Development and Construction Documents
Cupertino Electric	Electrical Subcontractor	Conduit and Cable Trays in 3D	3D Pipe Designer, NavisWorks	Design Development and Construction Documents
JW McClanahan Company	Plumbing Subcontractor	Plumbing System in 3D	3D Pipe Designer, NavisWorks	Design Development and Construction Documents
North Star Fire Protection	Fire Protection Subcontractor	Fire Protection System in 3D	FireACAD	Design Development and Construction Documents

2.1.3 Author’s Role on the Project

One of the authors, Atul Khanzode, was intimately involved in the MEP coordination process on the Camino project while working for DPR Construction. The author was a key member of the project team and participated part time during the MEP coordination process from April of 2005 to December 2005. The author also wrote a lessons learned report for the team that included the use of 3D tools for MEP coordination and the use of the Lean Project Delivery System on the project (Khanzode et al. 2005). The author’s role is summarized below (specific details are provided in subsequent sections):

- Helping the team define and setup the technical logistics on the project. The technical logistics involved defining how the servers would be setup to share the models, the file naming conventions for the model files, and how the model files would be integrated in 3D in Navisworks.
- Determining the phase schedule for coordination. This involved working with the MEP subcontractors and the architect and engineering (A/E) team to determine an overall schedule for the MEP coordination work.
- Determining the handoffs between designers and the subcontractors detailing team. This involved establishing the specific design scope that would be handed off to the subcontractors’ detailers from the A/E team.
- Integrating the 3D models created by the subcontractors detailing team. This involved gathering all the model files from the subcontractor’s detailers and then merging these files with the architectural and structural models.
- Identifying physical conflicts between models using NavisWorks Clash Detective program. This involved defining the batches for clash detection and selecting the appropriate systems. For example, clashes between HVAC ductwork and steel were determined by defining a batch in NavisWorks and selecting HVAC models to clash against the structural steel model. This was completed for all possible dual combinations of systems on the project.
- Publishing reports that identified the specific clashes and documented the action items for each clash that needed to be resolved. These reports were distributed to the project team to communicate the changes needed in each discipline’s 3D models to resolve the issues identified.
- Tracking the commitments from subcontractors towards completion of the outstanding issues. This

involved using the weekly work planning process where commitments were sought from the subcontractors and tracked for resolution.

- Creating 4D models based on the weekly work plans created by the subcontractors. This process is described in detail in section four of this paper.
- Participating in the coordination process to determine the installation sequence for the MEP work. This process is also described in detail in the context of 4D modeling for the MEP installation work.

2.2 The Sequus Project

The project's scope was to construct a pilot plant facility within an existing warehouse for Sequus Pharmaceuticals, a bio-tech company located in Menlo Park, California. The facility contains 20,000 square feet of available space, with 3,440 square feet of office space, 3,100 square feet of manufacturing space, 2,900 square feet of process development space, and 4,800 square feet of future expansion space. The MEP systems were designed such that the majority of the work was placed on an equipment platform. The platform was necessary because the existing structure was not capable of supporting the increased loads from the MEP systems and related equipment. Construction started in May 1998 and substantial completion was completed as scheduled on February 1, 1999. The negotiated contract price was approximately $6M. Fig. 2 shows the integrated 3D model.

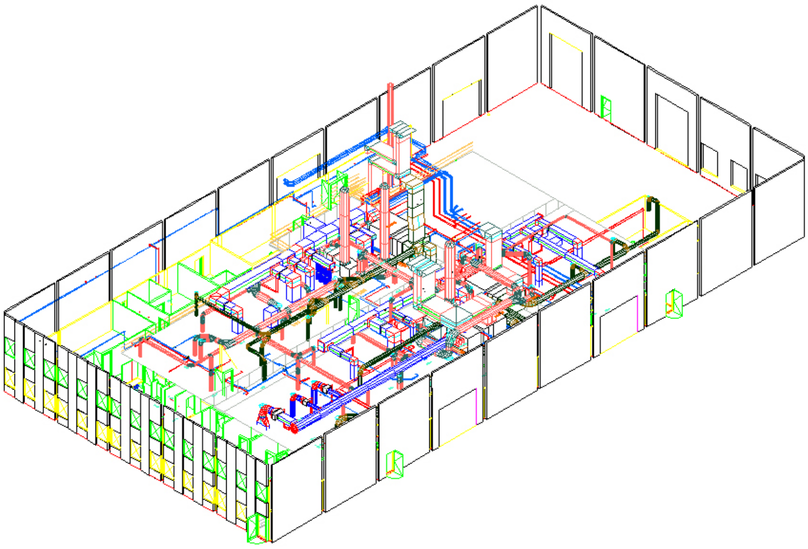


FIG. 2: Integrated 3D Model of the Sequus Pharmaceuticals Pilot Plant in Menlo Park, California.

2.2.1 Project Organization

The Sequus project was unique in that the general contractor assembled the design-build team prior to design and construction. The project team consisted of the following companies: the design firm Flad & Associates, the General Contractor Hathaway Dinwiddie Construction Company (HDCC), the engineering firm Affiliated Engineers Incorporated, the piping subcontractor Rountree Plumbing & Heating (RPH), the HVAC subcontractor Paragon Mechanical (PM), and the electrical subcontractor Rosendin Electric Incorporated (REI). The general contractor selected each member of the design-build team based on their experience using 3D CAD technology on past construction projects and previous experience working with each other. Each team member made a commitment to model their respective scope of work in 3D CAD using a design-build approach.

2.2.2 Modeling Responsibilities

In general, the design firm was responsible for managing the design process and creating the 3D model of the architectural scope of work. The general contractor was responsible for orchestrating and managing the distribution of electronic design information, design coordination, and managing the construction process. The engineering firm was responsible for providing the basis of design and schematic drawings for the mechanical, electrical, and piping work. The MEP subcontractors were responsible for the detailed design and 3D modeling of their scope of work.

Table 2 summarizes the modeling responsibilities for the various project participants. The unique aspect of the assignment of modeling responsibilities on this project is that the designs are created by the participants who are responsible for installation and can leverage the designs throughout construction. The engineers created the Basis of Design and the schematic drawings but the subcontractors did all the 3D modeling for the MEP systems. This collaborative design approach enabled each company to get feedback quickly on their designs. Participants were able to communicate directly with the other team members to explain their design intent. Each team member had an incentive to provide the 3D models and this feedback because they could leverage their own 3D models and the designs created by others to support their project management functions throughout the design and construction processes.

TABLE 2: Modeling Responsibilities for the Sequus Project.

Company	**Role**	**Modeling Responsibility**	**3D Software**	**Phase Model Created /Coordinated**
Flad and Associates	Architect	Architectural Modeling in 3D	Archt by Autodsys	Schematic Design
Affiliated Engineers Incorporated	Mechanical, Electrical, and Process Engineers	Basis of Design and Schematic Drawings for the MEP Systems	N/A	Schematic Design
Hathaway Dinwiddie Construction Co.	General Contractor	Overall Coordination of MEP Design	AutoCAD	Design Development
Rountree Plumbing & Heating	Plumbing Subcontractor	Mechanical and Process Piping in 3D, 3D MEP Coordination	Multi-pipe by UHP Process Piping	Design Development and Construction Documents
Paragon Mechanical	Mechanical Subcontractor	Ductwork and Mechanical Equipment in 3D	Autodesk Building Systems	Design Development and Construction Documents
Rosendin Electric	Electrical Subcontractor	Conduit, Cable Trays, and Lighting in 3D	AutoCAD	Design Development and Construction Documents

2.2.3 Author’s Role on the Project

The first author worked full time for Hathaway Dinwiddie Construction Company during design and construction of the Sequus Project. A significant part of her responsibilities focused on supporting the 3D design coordination process, enabling the use of the 3D models for different construction management purposes, and developing and managing the 4D model. Specifically, she supported the project team with the following activities:

- Worked with project team members to develop design guidelines to aid the electronic 3D design coordination process. These guidelines will be discussed in detail in the next section.
- Supported the electronic 3D design coordination process. This included integrating the 3D models for design coordination meetings, working with the different 3D models to facilitate design coordination, and maintaining a digital archive.
- Documented the results of the 3D design coordination meetings. This involved documenting the conflicts and solutions during the design coordination meetings. In some cases, it also involved the preparation of a summary report of the meeting discussion for distribution to other members of the team.
- Developed custom 2D and 3D models to support the General Contractor’s other project management functions. For example, the author prepared dimensioned 2D drawings of the concrete pads for the Air Handler Units using the 3D mechanical model.
- Identified drawing methods and data manipulation techniques to support design-cost integration of the 3D designs. Although not discussed in this paper, we also investigated the feasibility of integrating the different 3D models with cost estimating software (Staub-French and Fischer 2001).
- Developed and maintained the master construction schedule. This included working with the project superintendent, the project manager, and the subcontractors’ foremen to provide summary, detailed,

and look-ahead schedules to the various stakeholders.

- Created and maintained a 4D model to assist with coordination of day-to-day construction operations. This included working with the different subcontractors to represent each discipline's workflow and relevant activities, manipulating the different discipline-specific 3D models to facilitate the linking of 3D objects and activities, and updating the schedule and 4D model as the design and construction strategy changed and evolved. This will be discussed in detail in section 4.

3. 3D DESIGN COORDINATION

In a complex building project, building system coordination is a critical and challenging task. It involves the detailed layout and configuration of the various building systems such that it complies with design, construction, and operations criteria (Barton 1983, Tatum and Korman 2000). Specialty contractors are typically responsible for the coordination of MEP systems, including responsibility for checking clearances and identifying routes, fabrication details, and installation locations (Tatum and Korman 2000).

3.1 Current 2D Design Coordination Process

The design coordination process typically begins when the design and preliminary routing of the building systems are complete. The specialty contractors encounter common constraints that determine the system routing: the building structure, corridors, shear walls, fire walls, major equipment locations, and architectural requirements, such as ceiling type and interstitial space (Korman and Tatum 2001). Consequently, each specialty contractor routes their system to their advantage as they consider these constraints, which is reflected in the preliminary drawings. This includes minimizing the length of branches and number of fittings, choosing prime locations for major components, routing close to support points, and designing for most efficient installation by their own trade (Korman and Tatum 2001). The level of detail in the preliminary drawings often varies by trade. Typically, the HVAC and piping systems are sized at this stage whereas the electrical and fire protection are not. Consequently, some of the building systems are drawn to scale while others are drawn simply as lines with references to component sizes.

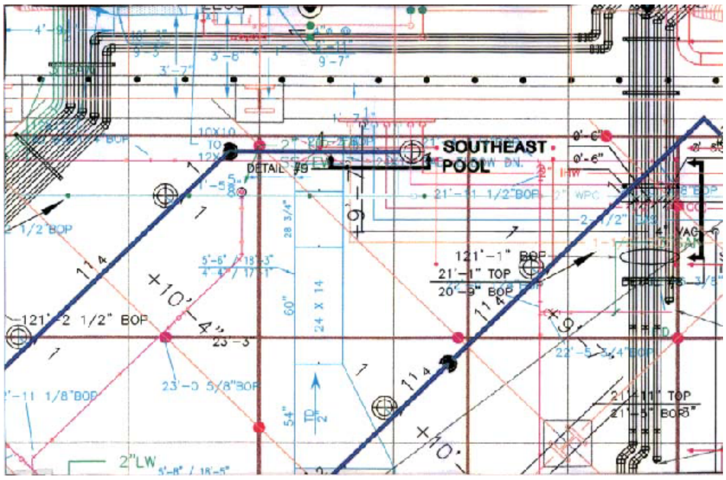


FIG. 3: Typical view of MEP systems coordinated in a 2D paper-based process.

Design coordination is an iterative process that starts with the specialty contractors bringing their preliminary drawings to a coordination meeting. The drawings are typically created in 2D and printed on transparent paper at 1/4-inch scale. During the coordination meeting, each specialty contractor places their 2D drawing on a light table to compare the different building system designs. Fig. 3 shows a typical view of MEP systems being coordinated using a 2D coordination process. The specialty contractors identify conflicts and develop solutions that are red-lined on the 2D drawings. This process continues until the coordination is complete and the specialty contractors sign-off on each other's drawings to signify their acceptance.

The current 2D paper-based design coordination is time-consuming, inefficient, and often leads to sub-optimal project performance as design conflicts are encountered and have to be resolved in the field. Creating and coordinating the designs in 3D allows project teams to integrate their designs electronically in the computer and identify conflicts in all three dimensions. Moreover, sharing electronic 3D models enables the project team to leverage the 3D design information throughout the design and construction process.

3.2 3D Design Coordination Process

Going from 2D to 3D design is a complicated process that requires a significant coordinated effort to fully leverage the benefits of 3D models. We identified the following ten steps as essential to setting up a 3D design process. These steps describe the optimal process based on the challenges we encountered:

1. Identify the Potential Uses of the 3D Models
2. Identify the Modeling Requirements
3. Establish the Drawing Protocol
4. Establish a Conflict Resolution Process
5. Develop a Protocol for Addressing Design Questions
6. Develop Discipline-specific 3D Models
7. Integrate Discipline-specific 3D Models
8. Identify Conflicts between Components/Systems
9. Develop Solutions for the Conflicts Identified
10. Document Conflicts and Solutions

3.2.1 Step 1: Identify the Potential Uses of the 3D Models

The project team should discuss the potential uses of the 3D models on a given project and identify the specific uses that will be implemented. For example, the 3D models could be used for thermal simulation, cost estimating, fabrication, shop drawings, user group visualization, etc. The use of the model often dictates the modeling requirements in terms of the level of detail and the modeling techniques that must be utilized. For example, if the architectural model is going to be used for thermal simulation then rooms must be explicitly modeled. If the model is going to be used for stakeholder visualization, then room details that are often important to user groups, such as light switches and electrical outlets, may also need to be modeled. If the model is going to be used for cost estimating, then the components must be modeled in a way that quantities can be extracted. If the model is to be used for creating fabrication and installation drawings then it also needs to include the correct objects that could then be pulled into a material requisition sheet and organized into a pre-fabrication work order (Fig. 4).

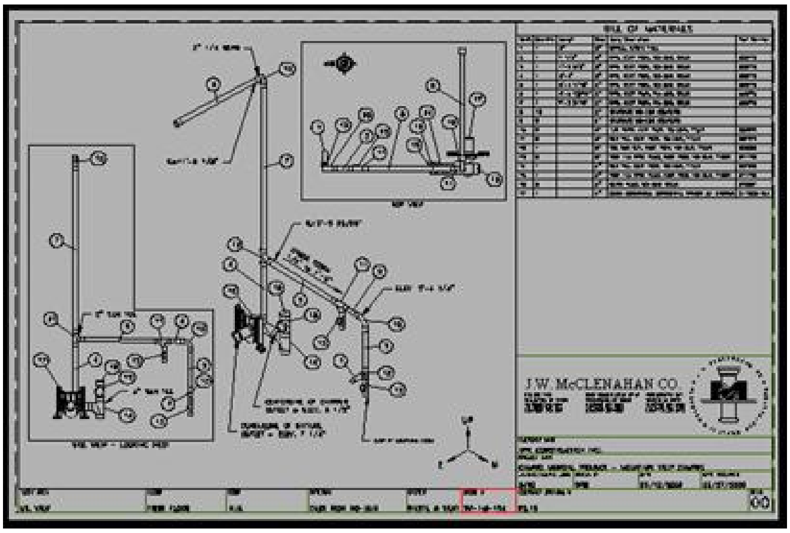


FIG. 4: Figure shows a pre-fabrication isometric drawing of a plumbing waste and vent assembly with the Bill of Materials that was generated automatically from the 3D Model on the Camino Project.

3.2.2 Step 2: Identify the Modeling Requirements

It is essential that the project team identifies who will create the 3D models, when the 3D models will be created, and how the 3D models will be created. Specifically, this step involves the following:

Identify the modeling responsibilities for the various scopes of work. This involves establishing the responsible party, and in some cases, the handoff or transition between parties. For example, on the Sequus Project the engineer was responsible for establishing the basis of design which excluded all CAD modeling, while the MEP subcontractors were responsible for creating the detailed 3D CAD models. Handoffs between parties become important if the scope of the 3D modeling efforts is shared by engineers and subcontractors. For example, on the Camino Project, the Mechanical Engineers modeled the HVAC systems to a certain point in 2D, and then the Mechanical Subcontractor detailed the scope in 3D.

Establish the scope of the 3D modeling effort and the level of detail to be modeled. To address this issue, project teams should consider the possible uses of the 3D models (step 1), as well as the cost and benefit of modeling a scope of work in 3D. For example, rebar could be modeled in 3D to facilitate procurement of these components but the benefits may not justify the expense. In contrast, the Structural Engineer on the Camino Project did not model the gusset plates in 3D, but these elements were critical for 3D coordination and should have been included.

Establish the work breakdown structure. It is important to identify how the models are going to be integrated and create a breakdown structure that is consistent and agreed upon by all parties. For example, on the Camino Project, the Medical Office Building was divided into 12 distinct quadrants, and the models were developed for each quadrant and coordinated by each quadrant.

Create a schedule that identifies key modeling activities. The schedule should specify when the models will be created, coordinated (conflicts identified), updated (conflicts resolved), and approved (ready for fabrication). Ideally, these milestones should be incorporated into the construction schedule and coordinated with related activities for installation.

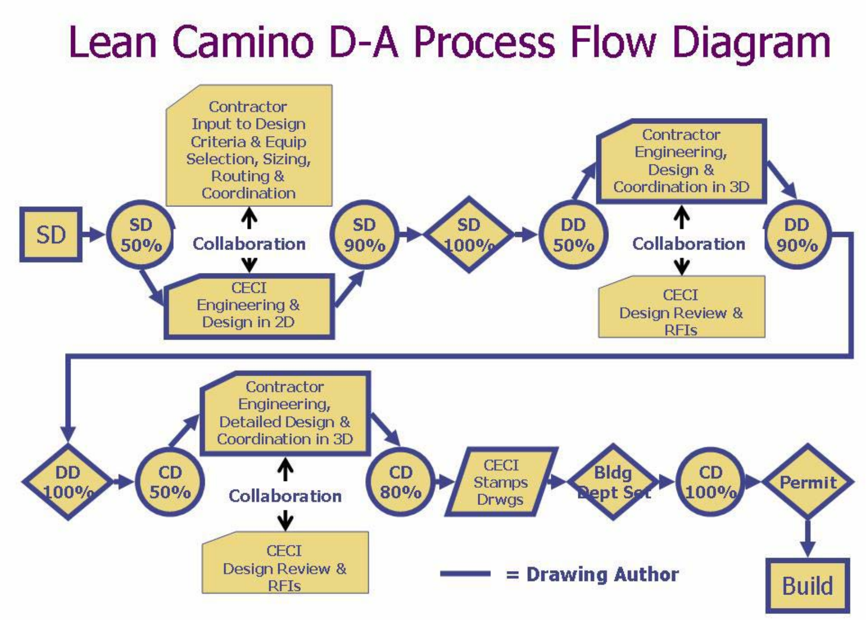


FIG. 5: Flow chart of design coordination process established on the Camino Project.

Fig. 5 shows a flow chart that illustrates the formal process established on the Camino Project for coordination and collaboration between designers, subcontractors, and the general contractor. The MEP coordination process was driven by the construction process. For example, MEP coordination was done by quadrant to meet with the schedule of installing inserts before the deck slab was poured, in a sense pulling design based on the construction sequence. Negative iteration in design was avoided by starting the modeling process early, and sharing incomplete designs early and often. The subcontractors also were encouraged to work directly with the designers to get answers to questions quickly rather than going through the traditional RFI workflow between subcontractor – general contractor – designer and back. An online system to make and keep track of all commitments was used as a substitute for the RFI process. This system called Commitment Manager acted as a conduit between the team and supported the Design process using 3D / 4D models efficiently.

3.2.3 Step 3: Establish the Drawing Protocol

To ensure that the 3D models can be electronically integrated and coordinated, the project team should establish a protocol that specifies the drawing conventions that will be implemented by all the parties.

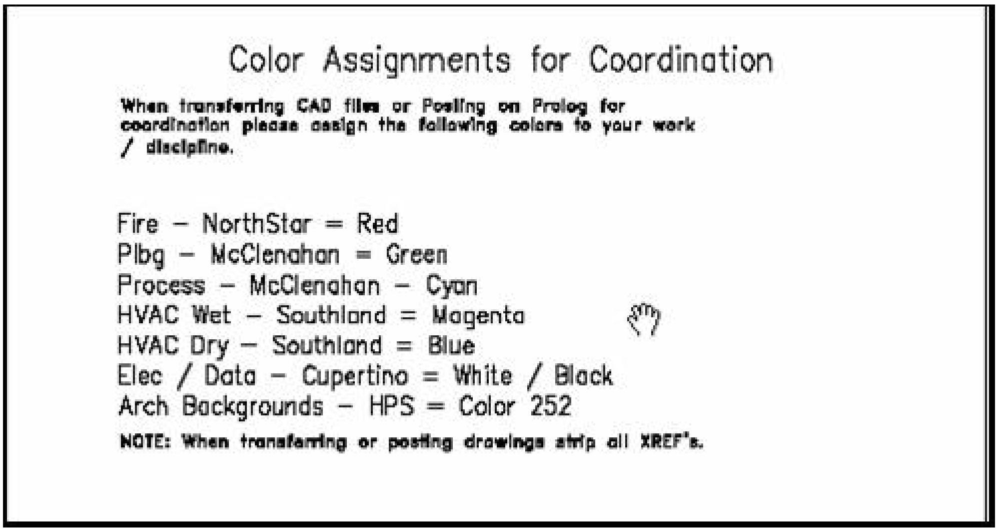
Project Reference Point (0,0,0): The project team must employ the same reference point so that the models integrate appropriately in all three dimensions. This is extremely important for 3D coordination otherwise the team will spend a lot of time trying to combine the models together for conflict detection purposes. For the Sequus and Camino Projects, the reference point was established by the design team, which was dictated by the architectural 3D model.

File Naming Convention: The file name should communicate the company that created the 3D model, the scope of the 3D model, and the version of the 3D model. On the Camino Project, we followed the AIA File Naming Convention but appended the initials of the subcontractor to the drawing. For example, the file name "M211A_SI.dwg" communicates the following: M = Mechanical, 2 = HVAC, 1 = 1st Floor, 1 = 1st Quadrant, A = Area, and SI = Southland Industries. However, this convention was not optimal for 3D coordination using Navisworks Clash Detective, therefore, we recommend that the company name be represented first in the file name if this software is being used.

Version Control: The version of the file can be represented in the file name by appending the file name with the date, or it can be handled separately through the use of folder names on FTP sites or collaboration sites.

Layering Convention: A layering convention should be established to facilitate 3D coordination. Any Object that requires separate coordination should be on a separate layer so that it can be viewed independently and easily turned on and off, which may include: text or annotations, structural grids, different systems (e.g., supply and return systems, junction boxes), flexible systems that can be easily routed (e.g., flex duct), and connections (e.g., sprinkler mains vs. heads).

Color Scheme: The color scheme should facilitate visual communication of the different scopes of work. Fig. 6 shows the color scheme established on the Camino Project, which shows the colors used for different systems and companies.



Color Assignments for Coordination

When transferring CAD files or Posting on Prolog for coordination please assign the following colors to your work / discipline.

Fire – NorthStar = Red
Plbg – McClenahan = Green
Process – McClenahan – Cyan
HVAC Wet – Southland = Magenta
HVAC Dry – Southland = Blue
Elec / Data – Cupertino = White / Black
Arch Backgrounds – HPS = Color 252

NOTE: When transfering or posting drawings strip all XREF's.

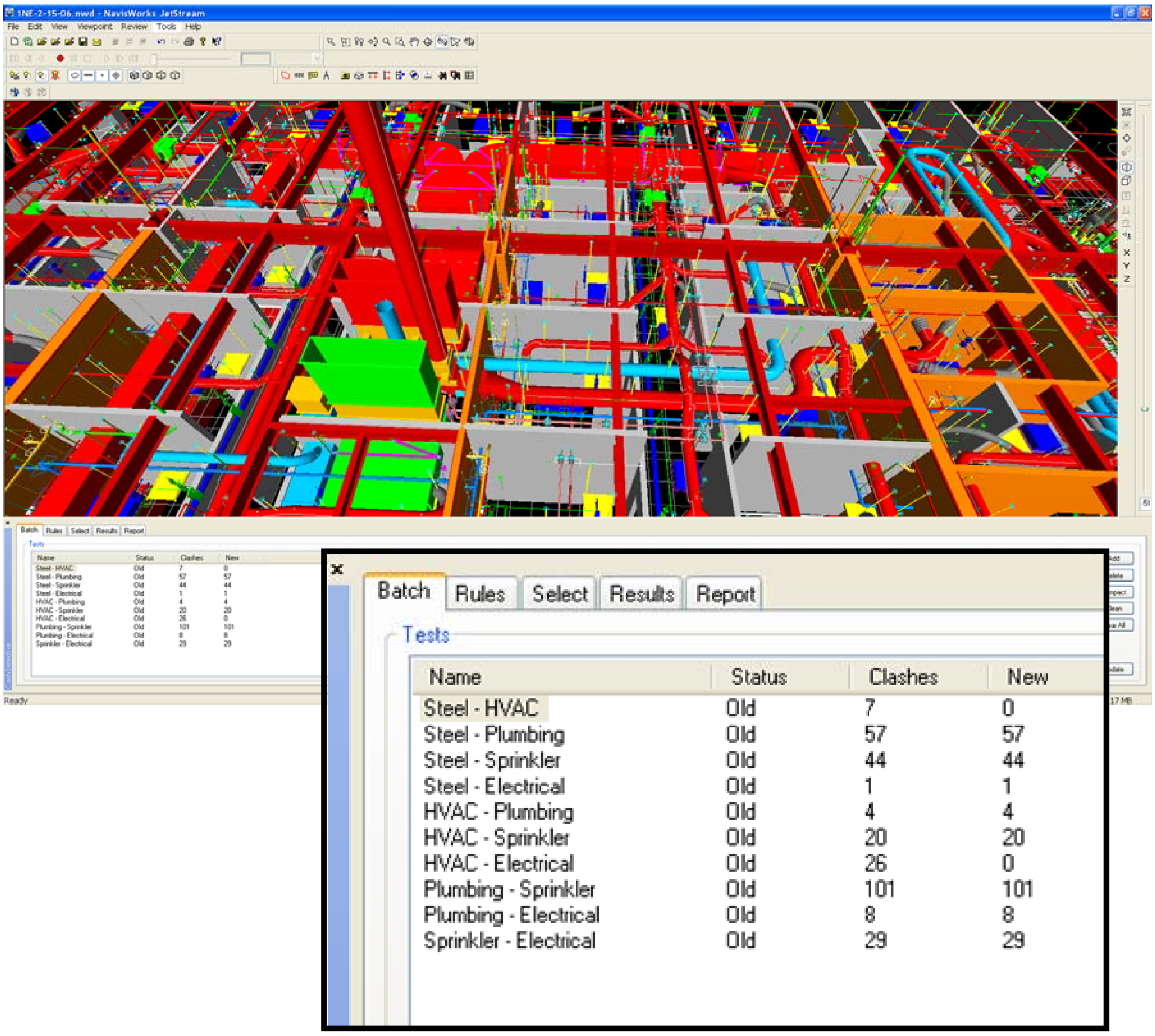
FIG. 6: Color Scheme used on the Camino Project for 3D coordination.

3.2.4 Step 4: Establish a Conflict Resolution Process

Setting up a process for identifying and resolving conflicts is extremely important to ensure that the team is making continuous progress towards a conflict-free solution on the project. In order to do this, there needs to be a system to detect conflicts between trades, document the conflict and the responsible party, and then resolve the conflict in the same sequence.

Identify the specific design review software that will be used during the 3D design coordination process. The software can be a CAD package (e.g., Autodesk Building Systems), or specific 3D coordination software (e.g., Navisworks Clash Detective). Although both packages facilitate the detection of physical interferences, we found that Navisworks Clash Detective was far superior in detecting some soft conflicts (e.g., interferences between physical components and clearance spaces), managing the process of detecting and resolving conflicts (e.g., conflicts can be tracked according to their status - new, active, approved, resolved, and old), and documenting the conflicts identified (e.g., conflict reports can be generated). Fig. 7 shows a snapshot of the Navisworks model for the Camino Project and the nine clash tests that were created to facilitate conflict detection between the systems.

Establish the process for sharing drawing files. We recommend that project teams use a formal collaboration website rather than an FTP site. In addition, we recommend that such a system facilitate both informal and formal information sharing. For example, the different disciplines should be able to pull the most recent model from the website when developing their 3D models, which doesn't require a formal coordination meeting.



Name	Status	Clashes	New
Steel - HVAC	Old	7	0
Steel - Plumbing	Old	57	57
Steel - Sprinkler	Old	44	44
Steel - Electrical	Old	1	1
HVAC - Plumbing	Old	4	4
HVAC - Sprinkler	Old	20	20
HVAC - Electrical	Old	26	0
Plumbing - Sprinkler	Old	101	101
Plumbing - Electrical	Old	8	8
Sprinkler - Electrical	Old	29	29

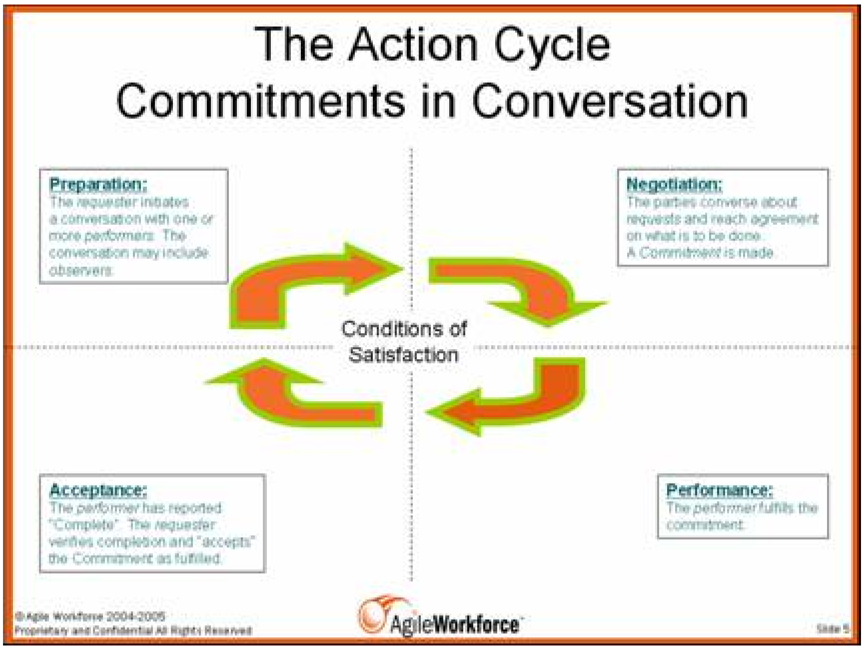
FIG. 7: Screenshot from the combined MEP/FP model for one of the quadrants from the Camino project and the 9 clash tests that were created.

Establish the timing and general meeting process for coordinating the 3D models. This should include the timing of meetings, timing of 3D model uploads, organizations involved, drawings to be coordinated, objects included (e.g., no text, no flex duct, no xrefs, specific systems, etc.), and systems to be coordinated (e.g., structural and HVAC).

Identify a responsible party to facilitate the electronic design coordination process. The responsible party downloads and electronically integrates the 3D drawings that are scheduled to be coordinated in the meeting. This typically includes drawings for the architectural, structural, piping, ductwork, lighting, and fire protection systems. The party responsible for this activity can vary but the key issue is making sure someone is responsible. On the Camino Project this was the responsibility of the General Contractor while on the Sequus Project this responsibility was given to the Mechanical Contractor.

3.2.5 Step 5: Develop a Protocol for Addressing Design Questions

This step is necessary if the contractors are responsible for developing the 3D models. We have learned that there needs to be a very clear and unambiguous mechanism in place for subcontractors and detailers who are working on developing the models to ask questions to the design team and resolve issues quickly as they come up, particularly on fast-track projects. We realized that the normal RFI process is inadequate when using the 3D models due to the unnecessary lag time for resolving issues. On the Camino Project, we adopted a web-based system called Commitment Manager, which the team members used to ask questions of each other (Fig. 8). We also agreed that during the Design Phase, the subcontractors and detailers should be able to pose a question directly to the most appropriate member of the design team rather than route it through the General Contractor in the form of an RFI so that valuable time is saved in resolving the issue.



The Action Cycle
Commitments in Conversation

Preparation: The requester initiates a conversation with one or more performers. The conversation may include observers.

Negotiation: The parties converse about requests and reach agreement on what is to be done. A Commitment is made.

Conditions of Satisfaction

Acceptance: The performer has reported "Complete". The requester verifies completion and "accepts" the Commitment as fulfilled.

Performance: The performer fulfills the commitment.

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Slide 5

FIG. 8: Screenshot of the Commitment Manager Action Cycle being used for making requests and answering questions on the Camino Project.

3.2.6 Step 6: Develop Discipline-specific 3D Models

Each discipline creates their respective 3D model using the discipline-specific design software used in their firm. Typically, the architect creates the architectural model first and then the other members of the team use the architectural model as the background when creating their 3D designs. Then, after the first coordination meeting, all members of the team can share and use each other's 3D models as a background. In this process, designs are being optimized from a coordination and constructability perspective as they are being developed. Therefore, coordination and constructability is not simply assessed at a specific point in time during design development, it is considered throughout the design development process.

3.2.7 Step 7: Integrate Discipline-specific 3D Models

The responsible party downloads and integrates the 3D models in preparation for the coordination meeting. On the Camino project, the project team used Navisworks to coordinate the building systems in 3D. The 3D models created using Quick Pen and CADDuct were combined into a single model in Navisworks and then the Navisworks Clash Detective module was used to define clash tests and identify clashes.

3.2.8 Step 8: Identify Conflicts between Components/Systems

A substantial amount of time in coordination meetings is spent trying to identify and resolve design conflicts. They are looking for "hard" conflicts, which are physical interferences between components, as well as “soft” conflicts, which are interferences between design components and access spaces or violations of clearances. Hard conflicts can be identified manually or automatically depending on the particular software being utilized. Fig. 9a shows a meeting between the General contractor and the Mechanical and Fire Protection contractors identifying all the conflicts between the Mechanical and Fire Protection systems for one of the quadrants of the building. Fig. 9 shows a hard conflict that was automatically identified between the Fire Sprinkler Pipe and the Supply Duct.

FIG. 9a: Formal coordination and conflict identification meeting between the General Contractor and the Mechanical and Fire Protection contractors on the Camino Project.

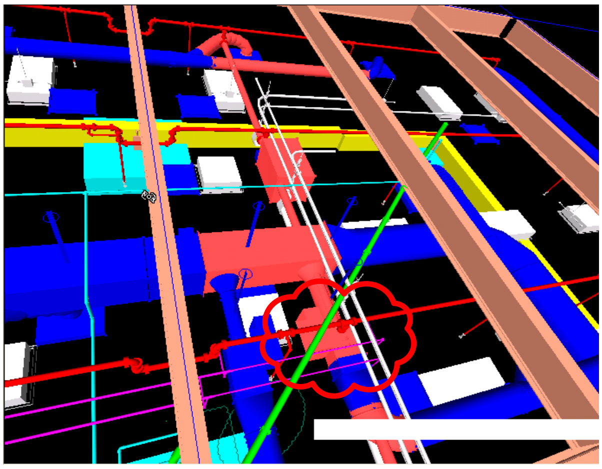


FIG. 9b: Hard conflict between the Fire Sprinkler Pipe and the Supply Duct that was automatically identified in Navisworks Clash Detective on the Camino Project.

On the Sequus Project, the team focused on certain areas and building systems and identified conflicts manually. For example, in one meeting, the detailer and foreman for Rountree Plumbing met with the detailer for Paragon Mechanical to coordinate the piping and ductwork connections around the air handler units with the 3D models in the computer (Fig. 10a). Although this process enabled the team to identify most conflicts, it would have been more efficient to identify such conflicts automatically.

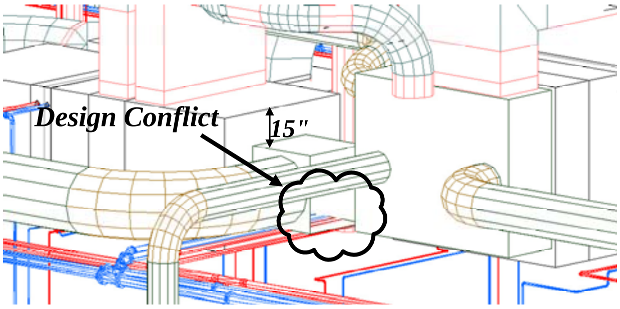


FIG. 10a: Design of connection to Air Handler Unit and conflict identified on the Sequus Project.

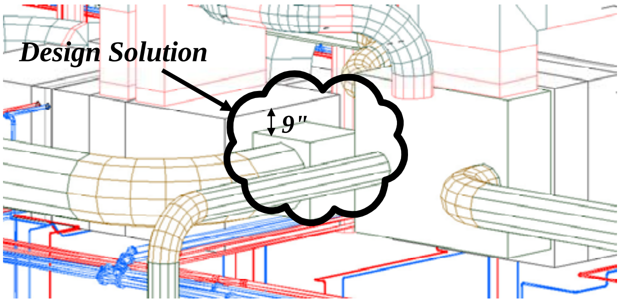


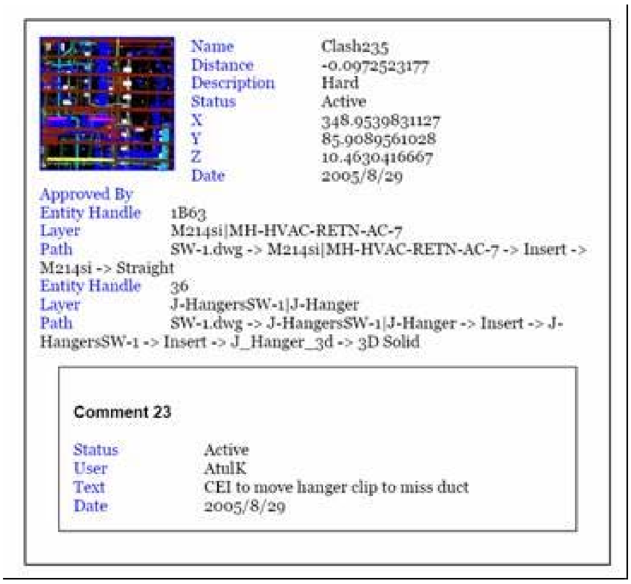
FIG. 10b: Revised conflict-free design of connection to the Air Handler Unit that was developed on the Sequus Project.

3.2.9 Step 9: Identify Solutions for the Conflicts Identified

After conflicts were identified, the team jointly develops a solution that works for all parties involved. Fig. 10b shows the solution to the design conflict at the air handler connection shown in Fig. 10a which was encountered on the Sequus Project. This design solution called for raising the air handler connection by 6" to avoid the piping. This design solution was detected early in the design coordination process and the AHU manufacturer implemented the change at no additional cost.

3.2.10 Step 10: Document Conflicts and Solutions

It is important to document the conflicts addressed in the coordination meetings including, the design conflict (a snapshot or clash report from Navisworks), the proposed solution, the responsible party, the systems that were coordinated, the drawing files used (for version control), the meeting date, and the organizations/people involved in the coordination process. On the Camino project we used the Navisworks software to create a conflict identification and resolution report that listed a particular conflict and how it was to be resolved by the next iteration (Fig. 11). This document was used to identify and resolve the clashes. The report was generated directly out of Navisworks.



Name	Clash235
Distance	-0.0972523177
Description	Hard
Status	Active
X	348.9539831127
Y	85.9089561028
Z	10.4630416667
Date	2005/8/29
Approved By	
Entity Handle	1B63
Layer	M214si|MH-HVAC-RETN-AC-7
Path	SW-1.dwg -> M214si|MH-HVAC-RETN-AC-7 -> Insert -> M214si -> Straight
Entity Handle	36
Layer	J-HangersSW-1|J-Hanger
Path	SW-1.dwg -> J-HangersSW-1|J-Hanger -> Insert -> J-HangersSW-1 -> Insert -> J_Hanger_3d -> 3D Solid

Comment 23

Status	Active
User	AtulK
Text	CEI to move hanger clip to miss duct
Date	2005/8/29

FIG. 11: Conflict identification and resolution report from the Camino Project generated directly from Navisworks Clash Detective.

3.3 Benefits

The following summarizes the key benefits of designing and coordinating building systems in 3D, and when possible, gives an example of each benefit realized on one of the projects.

- **Most design conflicts are identified prior to construction:** By modeling in 3D and electronically integrating the 3D models, design coordination and constructability analysis is performed with a more accurate representation of the building systems. On the Camino and Sequus projects, this process is further enhanced because the participants with the construction expertise that had the most to benefit from the models were actually designing and coordinating the 3D models. Moreover, many conflicts are avoided because the different disciplines are using each other's 3D models as they design.
- **Productivity is significantly improved:** Most design conflicts are identified and resolved prior to construction enabling a more efficient and productive installation process. In addition, many of the mechanical systems can be fabricated directly from the 3D model in the shop, which can lead to significant productivity gains. On the Sequus Project, the mechanical contractor used the 3D models extensively for field coordination and daily planning of construction activities, resulting in a substantial increase in field productivity. As stated by the Project Manager: "Field productivity was improved. Even on a system where we did not attempt to do any prefab, the installers were able to refer to small area isometric drawings to facilitate installation." On the Camino Project, the productivity for the mechanical subcontractor was significantly improved. They estimate approximately 25-30% improvement in productivity compared to their estimated productivity for installation of duct and piping scopes of work on traditional projects (Fig. 12).

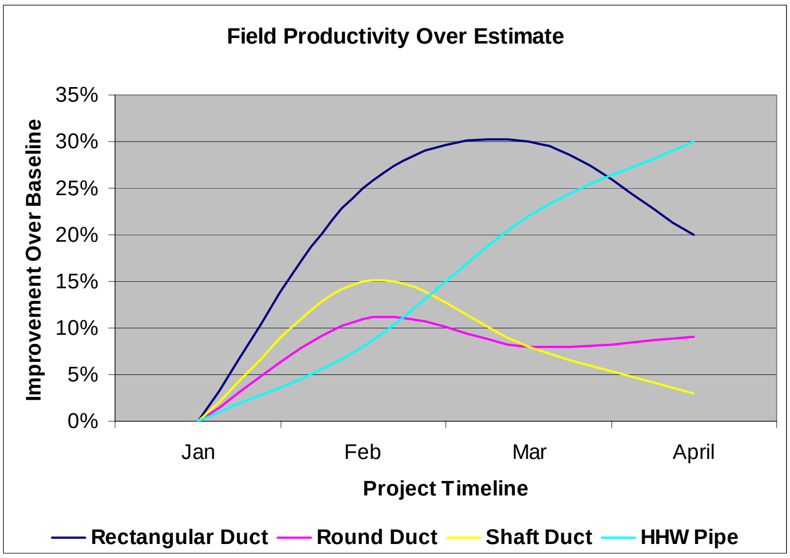


FIG. 12: Comparison of field productivity versus estimated productivity for the Camino project for installation of ductwork and heating hot water pipe (courtesy of Southland Industries, 2006).

- **Less Rework:** The MEP design coordination process eliminates most of the design conflicts prior to construction. Typically, many conflicts go undetected until they are encountered during installation, often resulting in expensive rework. On the Sequus Project, the only rework that was required occurred between trades that did not model their scope of work in 3D. In fact, the superintendent for the general contractor noted the "seamless" installation process for the 3D work. On the Camino project, after 250,000 square feet had been constructed, there was not a single field conflict during the installation of the MEP / FP work. According to the Superintendent, he has never experienced this level of accuracy of field installation before in his 35 years of experience and estimates that he is spending much less time resolving field issues compared to past projects. He estimates that on past projects he used to spend 2 to 3 hours per day dealing with these issues, and on Camino he has spent a total of 10-15 hours over an eight month period after the MEP installation began.
- **Increased opportunity for Pre-fabrication:** We believe that modeling and coordinating the MEP / FP systems in 3D provides a better opportunity to pre-fabricate materials in a shop environment. For example on the Camino Project, all of the plumbing systems (piping for water, waste and vent) were pre-fabricated. Normally the piping is cut in the field. All the low pressure duct system was also pre-fabricated. Normally only the medium pressure duct is pre-fabricated and the low pressure smaller duct runs are field assembled. On the Sequus Project, the Mechanical Contractor was able to fabricate many of the different pipe runs from the 3D models, resulting in time and cost savings and fewer errors. This was particularly useful for the extremely expensive piping that is used in Sequus' manufacturing processes. For example, stainless steel pipe can cost approximately $400/LF in cramped spaces, such as mechanical rooms, and $125/LF in open spaces, such as laboratories, according to the project manager for Rountree Plumbing. If one measurement is off in such complicated piping systems, it could cost approximately $700 to fix each mistake. In addition, the large 4” and 6” piping around the chillers was labor-intensive to install and expensive to cut. The 3D models allowed Rountree Plumbing to have the supplier fabricate the pipe in the shop at about 1/3 of the cost. The project manager for Rountree Plumbing stated that "virtually everything prefabricated from the 3D model was installed as planned."
- **Fewer Requests for Information (RFI):** There are primarily two reasons why there can be significantly fewer RFI's on 3D projects: 1) the designs are coordinated and conflicts are identified early in the construction process (as described above), and 2) the MEP subcontractors are responsible for the detailed design of their scope of work. By creating detailed 3D models in the design phase, the MEP subcontractors are able to work out how the components would fit together and how the building systems would interface. In a traditional process, these issues would often be

resolved through the RFI process. On the Sequus Project, there were 60% fewer Requests for Information (RFI) than expected for a project of this complexity. On the Camino project, out of 233 RFI's, 160 were confirming RFI's, about 10% related to the MEP / FP coordination work where the 3D models were used for coordination, and only two were related to field conflict issues..

- **Fewer Change Orders:** Rework is often a big cause for the many change orders that typically originate during construction. On both the Sequus and Camino projects, there were significantly fewer change orders than expected for such complex projects. On the Sequus Project, there was only one contractor-initiated change order for the scope of work modeled in 3D, which is remarkable for work of this complexity. On the Camino Project, there were zero change orders related to field conflicts after the construction of MEP systems for the first six quadrants.
- **Design errors can be identified prior to construction:** On the Sequus project, we identified a design error that could have potentially caused substantial rework. An AEC chiller was incorrectly designed in 3D at about 20% its actual size. When this mistake was corrected, the chiller no longer fit in the space allocated requiring the piping to be re-routed to a new location. This conflict was resolved three months before the chiller was scheduled for installation.
- **Ability to build the system with a less skilled labor force:** We believe that modeling and coordinating the MEP / FP systems in 3D provides an opportunity to create more of an IKEA type assembly rather than trying to interpret complex drawings to build a system. On the Camino Project, this has allowed the team to use a less skilled labor workforce to bolt together systems which would normally require experienced plumbers. For tight labor markets like California, less skilled labor is often required and it is imperative that tools like 3D / 4D be used to maintain the quality of installation.
- **Improved Safety Performance:** A fully coordinated model facilitates a smoother workflow by helping teams to identify their work area requirements and plan logistics resulting in a much safer jobsite. On the Camino Project, there was only one recordable injury after 178,000 person-hours.
- **Better cost control:** On the Camino Project, the MEP / FP subs have adjusted their cost downwards in finalizing their contracts due to the increased productivity that has resulted from a highly accurate bill of materials and increased pre-fabrication on the project. We believe that this has resulted in a much better cost control for the subs performing the work on the project. On the Sequus Project, cost control was a key concern for the owner. Typical cost growth on projects of this complexity range from 2% - 10%, with 2% considered extremely successful, according to the Sequus project manager. The cost growth on the Sequus Project averaged 1% for the MEP subcontractors, which was mostly due to owner initiated design changes.

3.4 Lessons Learned

On each of these projects, the project team learned many valuable lessons that were critical to the success of the integrated 3D approach that should be incorporated on future projects. These lessons learned are summarized below:

- Project teams should determine the stage in the design development process when a specific scope of work should be modeled in 3D. The sequencing and timing of the design development process needs to coincide with the design coordination process, the procurement process, and the construction process, particularly in design-build environments. On the Camino Project, we learned that the structure should be modeled in 3D before the 3D coordination for MEP trades can start, and that the HVAC duct needs to be 75% complete before the other trades can really be productive in routing their utilities as the duct is the most constraining. In addition, one other lesson learned from Camino is that for multi-storey buildings it is extremely important that the gravity system be decided very early in the project, otherwise changes to higher floors impact the design of lower floors.
- Project managers and executives committing to a team-oriented approach should carefully assemble their project staff. It is critical that each discipline's project team understands the goals of the project, the level of information sharing needed, and the level of 3D modeling required.
- Assemble teams so that the designs are created by the participants who have the construction expertise to create constructable designs, and who are responsible for installation and can leverage the designs throughout construction. A collaborative design approach also provides incentives for

team members to provide feedback on the other discipline's designs because they can leverage the designs created by others to support their project management functions. We recommend pre-qualifying all the team members for their capability to produce 3D drawings and work in 3D.

- When setting up a 3D project, it is preferable to have one person or one company that is responsible for the electronic design coordination meetings. Ideally, the company responsible for the 3D coordination meetings will also be responsible for MEP coordination in general. On the Sequus Project, however, the mechanical contractor was responsible for electronically integrating the 3D drawings that were scheduled to be coordinated in the meeting while the General Contractor was responsible for the MEP coordination process, which led to inconsistencies in the management of this process.
- Every essential trade on the project should put their design (scope of work) into the 3D model to leverage the benefits of electronic 3D design coordination. On the Sequus Project, the structural work was only partially modeled in 3D and the fire sprinkler work was not modeled at all in 3D, resulting in the only design conflict problems during construction.
- Project teams modeling in 3D require increased design and coordination time. Although this is offset by benefits in construction, it does need to be addressed in each discipline's estimate and contract. On the Sequus Project, the mechanical trades reported a 30% increase in design time.
- It is important that all team members agree on a coordination and conflict resolution process. There needs to be a formal process in place for addressing the conflicts and issues identified in the 3D MEP coordination process. On the Camino Project, we learned that when using Navisworks Clash Detective it is best to proceed with clash detection in a sequence otherwise fixing one clash has the potential to generate other clashes. Also, it is important to keep track of who is fixing what using the Clash Report. Also, defining a process that can guarantee reduced latency to answer design questions raised by the subs during the modeling process is key to success and allows the subs to keep working on their models.
- Most of the professionals involved, from the designers and consultants to the subcontractors and trades and foremen, are used to communicating and understanding a 2D presentation of the design. To facilitate acceptance and understanding of the 3D models, project teams should provide both 2D and 3D representations when adopting this type of process.
- Issues and conflicts identified in an MEP coordination meeting need to be documented in a way that facilitates ease of use and interpretation. The 3D model alone does not provide this type of documentation. There needs to be a complementary document that provides the necessary annotations and labeling to convey the issues identified and their resolution.

4. CONSTRUCTION COORDINATION

This section describes the current practice of creating and maintaining construction schedules and contrasts it with the 4D process used on the Sequus and Camino projects. We describe the specific steps required to create 4D models, the issues that must be addressed to ensure successful implementation, and the benefits and limitations of 4D technologies.

4.1 Current Practice

A major task for construction planners is to determine the sequence of construction activities so that resources are allocated appropriately and coordination of sub-trades is optimized. Current project management practice uses CPM (Critical Path Method) schedules to represent the completion of a facility design over time. CPM schedules show the dependencies between activities, but they do not provide a link between the three dimensions of space and the fourth dimension of time. Yet the interdependency between this information is critical for planning, evaluating, monitoring, and coordinating the construction process.

Most construction managers, through years of experience, are able to visualize the construction process in their heads. Communicating that conceptualization of the construction process, however, is ineffective with traditional CPM networks and bar charts, resulting in differing perceptions about how the work will actually be installed in the field. Consequently, many problems go undetected resulting in reactive project management and sub-optimal project performance as problems get resolved during construction. To proactively manage the construction process, project teams need to be able to visualize the four dimensional nature of the construction process.

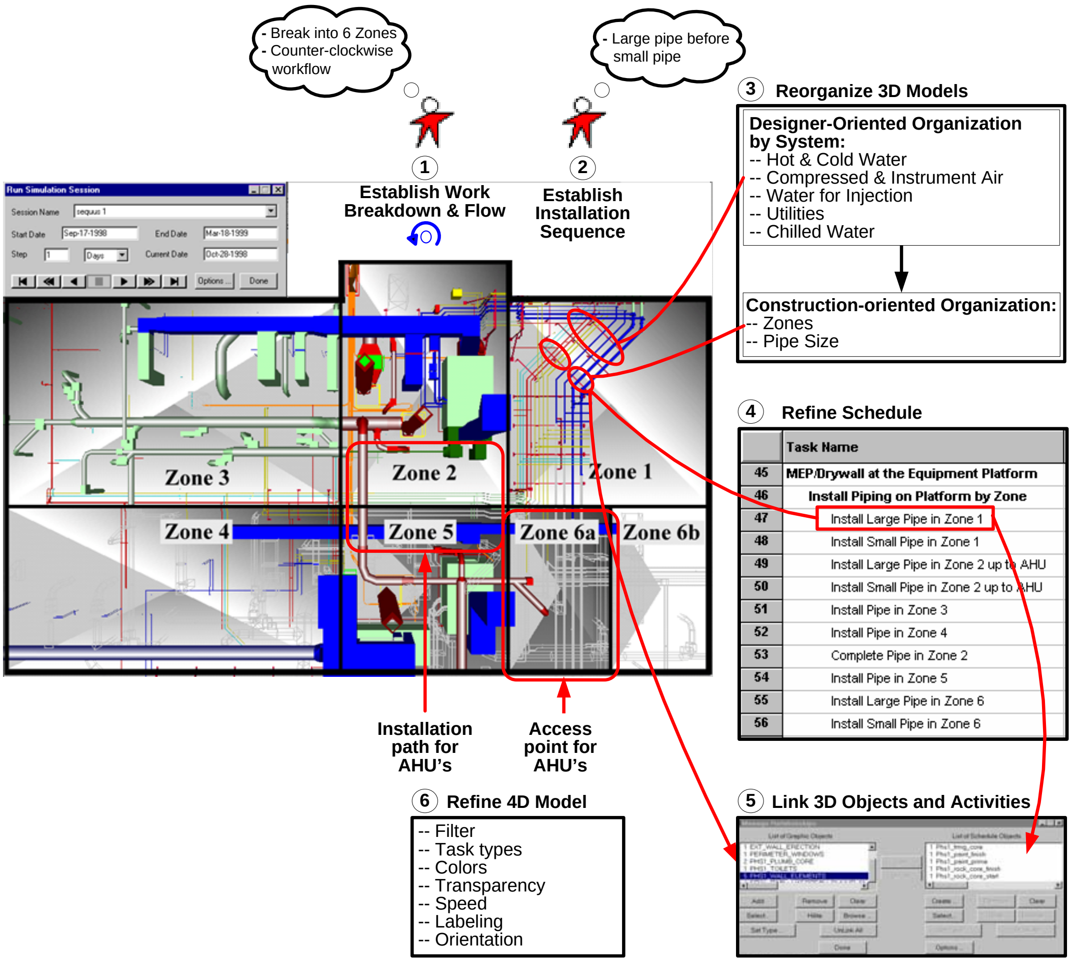
4D-CAD (3D + time) is a tool that links 3D CAD objects with construction activities and allows project teams to visualize the construction process as a computer animation. As a result, project teams are better able to evaluate the spatial needs of each discipline over time, thus improving communication and coordination between sub-trades (Koo and Fischer 2000, Haymaker and Fischer 2001).

The next sections describe how 4D models were created and used on the Sequus and Camino Projects. We describe the different tasks that are required to create a 4D model, and then describe the different techniques used on each of the projects to accomplish those tasks.

4.2 4D Construction Coordination Process

One of the goals of the coordination process on both the Sequus and the Camino projects was to limit the interaction between the subcontractors installing the different systems so rework could be avoided and productivity maximized. The 4D model was used for this purpose. We identified the following six steps as essential to developing a coordinated and detailed 4D model for construction coordination. Fig. 13 shows these steps using the Sequus project as an example. On the Sequus project, the 4D model was created by the General Contractor using Bentley's Schedule Simulator software and on the Camino project the 4D model was created using NavisWorks JetStream Timeliner software:

1. Establish Work Breakdown and Flow
2. Establish Installation Sequence
3. Reorganize 3D Models
4. Refine Schedule
5. Link 3D Objects and Activities
6. Refine 4D Model



Session Name: sequus 1
Start Date: Sep-17-1998
End Date: Mar-18-1999
Step: 1 Days
Current Date: Oct-28-1998

Designer-Oriented Organization by System:
-- Hot & Cold Water
-- Compressed & Instrument Air
-- Water for Injection
-- Utilities
-- Chilled Water

Construction-oriented Organization:
-- Zones
-- Pipe Size

	Task Name
45	**MEP/Drywall at the Equipment Platform**
46	**Install Piping on Platform by Zone**
47	Install Large Pipe in Zone 1
48	Install Small Pipe in Zone 1
49	Install Large Pipe in Zone 2 up to AHU
50	Install Small Pipe in Zone 2 up to AHU
51	Install Pipe in Zone 3
52	Install Pipe in Zone 4
53	Complete Pipe in Zone 2
54	Install Pipe in Zone 5
55	Install Large Pipe in Zone 6
56	Install Small Pipe in Zone 6

-- Filter
-- Task types
-- Colors
-- Transparency
-- Speed
-- Labeling
-- Orientation

FIG. 13: Primary steps required to create a 4D model using the Sequus Project as an example.

4.2.1 Step 1: Establish Work Breakdown and Flow

The first step in the creation of a 4D model is to identify how the work is broken down and how it will flow through the project for the various subcontractors. This process involves working with the subcontractors' trade foremen who are planning the work. On both projects, the GC consulted the foreman for each of the three MEP trades and the superintendent to determine what activities were necessary, how the work would be sequenced, and how work would flow through the project.

On the Sequus Project, the 4D model was used to coordinate the mechanical, electrical, and piping work with the equipment installation on the mechanical platform. It was necessary to show the access point and installation path for the AHU's (Fig. 13) as well as the areas that must remain clear. For example, the piping subcontractor would not be able to install the different pipe runs continuously as planned. Rather, he had to postpone the installation of the piping that ran between the AHU's (zones 2 and 5) because it interfered with the space required for the AHU's installation path. The GC consulted the foreman for each of the three MEP trades and the superintendent to determine the overall flow of work. Based on these conversations with the sub-trades, the area was broken down into six zones with work flowing in a counter-clockwise direction (see Fig. 13). The MEP work in part of zone 2 and all of zones 5 and 6 would have to wait until after the AHU's were installed.

On the Camino project, the overall break down of the work was developed by the Foremen for each trade and the General Superintendent. The project was divided into 4 separate quadrants and a center area for each floor (Fig. 14). The construction sequence was developed so that for each floor the South side was built first and then the north side. A phase schedule was developed to determine the flow of work and handoffs between trades for each quadrant. For each of the three floors, construction was started at the South East End and flow was determined to go from SE-SW-NE-NW and then through the center. This allowed for efficient movement for the materials as the center area was used for staging and was the main access point for all quadrants.

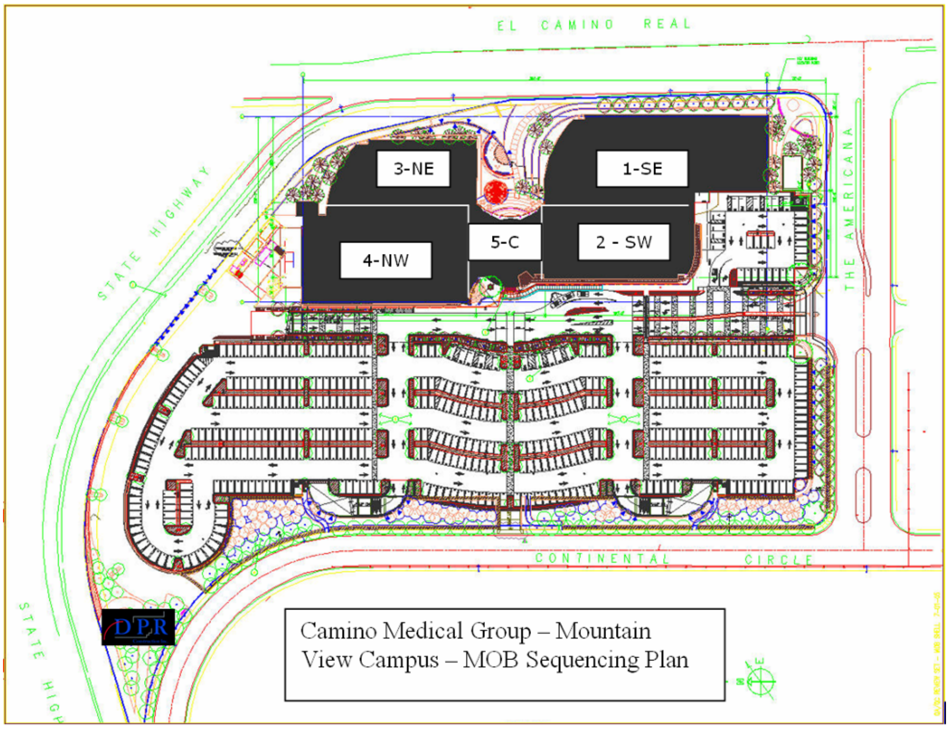


FIG.14: The sequencing plan for the Camino Project showing work proceeding clockwise from the southeast corner (1-SE) and finishing in the center (5-C).

4.2.2 Step 2: Establish Installation Sequence

After the work breakdown and flow has been established, the next step is to determine the installation sequence within each of the smaller work areas. The installation sequence is established by consulting with the different sub-trades and the project superintendent to identify the activities that need to be executed by the different disciplines and the relationships between activities and trades for each work area. On the two projects we studied, the installation sequence was the same for each work area but that may not always be the case.

On the Camino project, the GC first determined the installation sequence for each area by each trade. The sequence of installation was determined so as to ensure that each crew can achieve maximum productivity by not having some other trade block their work. The following sequence of work was decided for each quadrant:

- Frame full height priority walls
- Install sprinkler pipe
- Install heating hot water pipe
- Install medium pressure duct
- Install low pressure duct
- Install plumbing graded lines, waste and vent
- Install cold and hot water piping
- Install electrical conduits, branch lines and cable tray

On the Sequus Project, the General Contractor consulted the foremen for the different trades to determine the general sequence of activities in each of the six zones on the equipment platform:

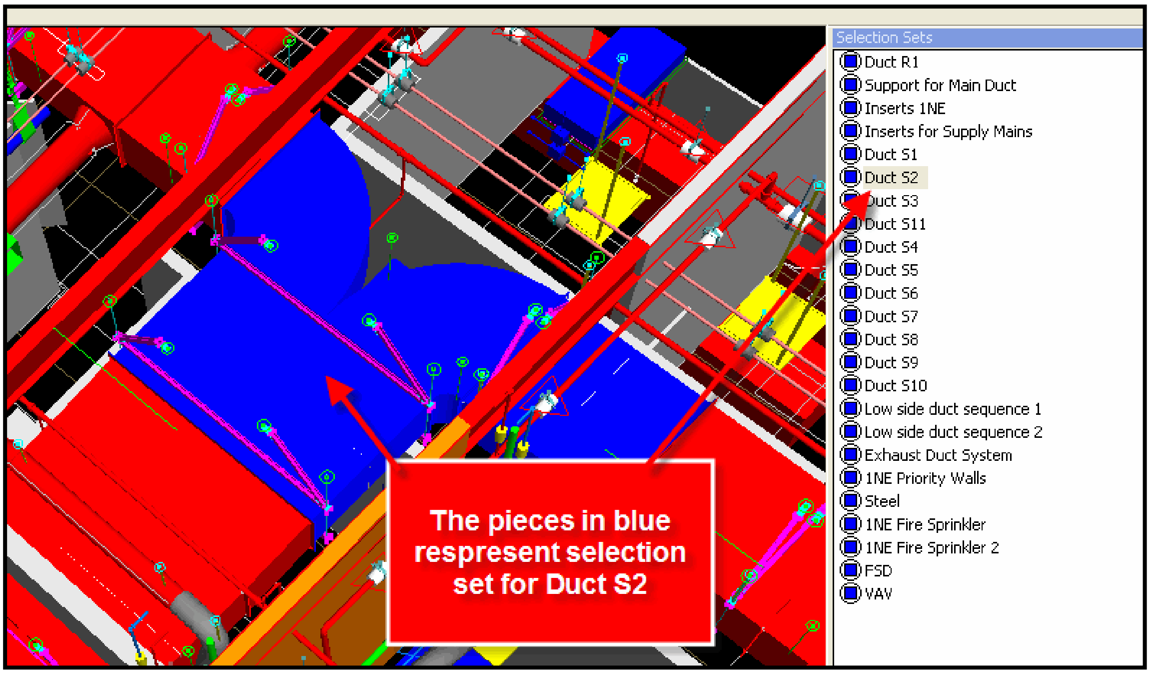
- Frame/drywall full height walls
- Install high rectangular and round duct
- Install risers
- Install large pipe
- Install small pipe
- Install low rectangular and round duct
- Install hard conduit

4.2.3 Step 3: Reorganize 3D Models

The third step in the process requires the reorganization of the 3D model so that the activities determined in Step 2 can easily be linked to the right 3D components in the model. This is necessary because the 3D models represent the design perspective (e.g., pipes are organized by system) and in a 4D model, we are trying to represent the construction perspective (e.g., pipes are organized by construction zone and pipe size), as shown graphically in Fig. 13. This task is typically the most time consuming part of developing a 4D model.

On the Sequus project, we used Bentley's Schedule Simulator to create the 4D model. We used the 3D models created by the architect and MEP subcontractors, and the master schedule created by the GC (step 4). Using Schedule Simulator, we found that it was easiest to map CAD layers to construction activities. Accordingly, each layer in the 3D model needed to be organized so that it corresponds to an activity in the schedule (e.g., move objects from the "Chilled Water Piping" layer to a new layer "Large Piping_Zone 1"). Consequently, we created new layers, renamed old layers, and moved CAD objects to the appropriate layer. For example, in the electrical drawing, there were two separate layers for wiring for lighting and wiring for power. For scheduling purposes, one wants to distinguish wiring by whether it is in the ceiling or in the wall. Therefore, the corresponding layers and objects had to be changed to "wall rough-in" and "ceiling rough-in". In addition, the 3D CAD models also had to be transformed to incorporate the work flow through the equipment platform. Consequently, the 3D CAD models had to be reorganized so that the scope of work related to each of the six zones was assigned to a separate layer. To illustrate the extent of changes required for this step, the HVAC design model originally contained six layers. After the model was modified to correspond to the schedule activities, there were 22 layers. This process was performed on five piping drawings for the different process piping and wet-side mechanical systems, the HVAC drawing for the ductwork and AHU's, and the structural drawing containing the concrete decking. If any one of these designs changed, this step had to be repeated.

On the Camino project, this step involved creating a grouping of objects by using functionality called "Selection Sets" in Navisworks Timeliner based on the information received from each trade foreman in step 2. Selection Sets act as groupings of 3D objects and are necessary to link multiple 3D objects to a single construction activity. Fig. 15 shows the Selection Sets (on the right) for the Mechanical work. The figure shows Duct S2 highlighted in Blue. In this example, the model is a combination of small duct pieces, but the way the duct will be installed depends on how the duct components are joined in a pre-fabricated assembly. Duct S2 is a combination of two elbow pieces and a rectangular duct and will be installed as one pre-fabricated assembly, which means there is a single activity in the schedule to represent the installation of Duct S2. The Selection Set Duct S2 combines the multiple duct objects into a single object (or object set).

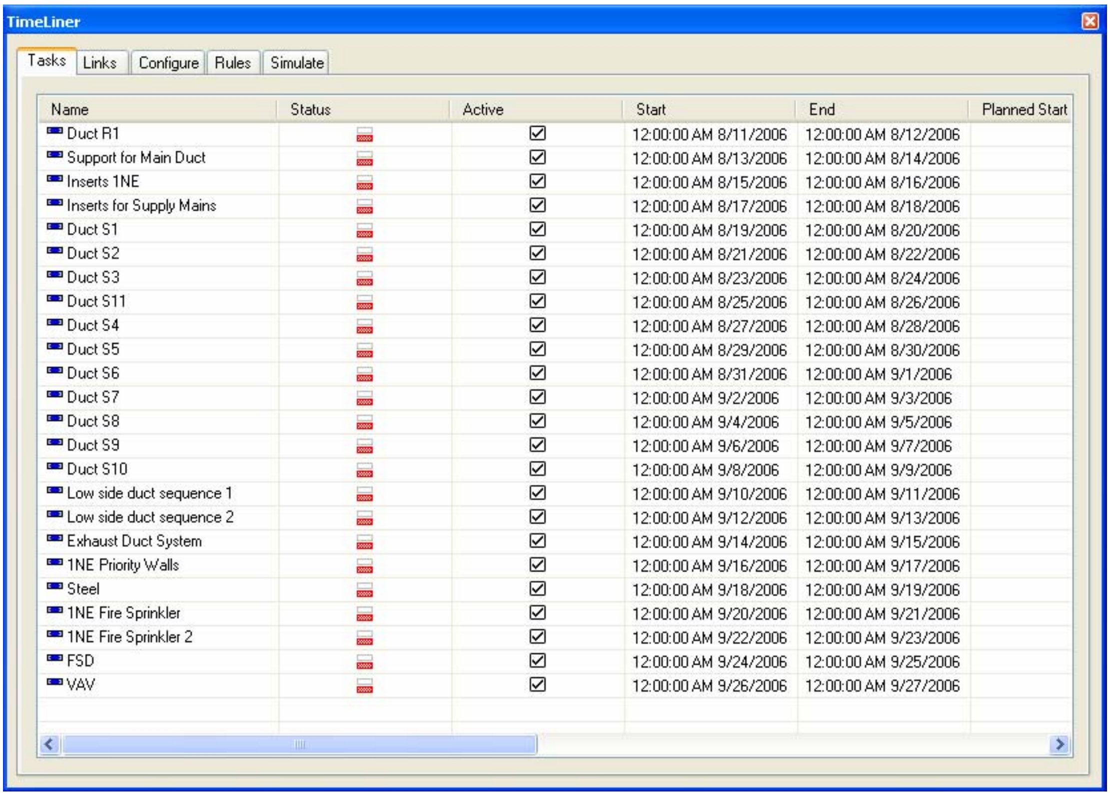


The pieces in blue respresent selection set for Duct S2

FIG. 15: Selection Sets created using Navisworks Timeliner that represent groupings of 3D objects.

4.2.4 Step 4: Refine Schedule

After the installation sequence was decided, the schedule has to be refined to represent the actual sequence of activities for each work area. To represent this more detailed sequence of activities, one can either revise the master schedule (as in the Sequus Project) or create a separate schedule for this scope (as in the Camino Project).



Name	Status	Active	Start	End	Planned Start
Duct R1	▤	☑	12:00:00 AM 8/11/2006	12:00:00 AM 8/12/2006	
Support for Main Duct	▤	☑	12:00:00 AM 8/13/2006	12:00:00 AM 8/14/2006	
Inserts 1NE	▤	☑	12:00:00 AM 8/15/2006	12:00:00 AM 8/16/2006	
Inserts for Supply Mains	▤	☑	12:00:00 AM 8/17/2006	12:00:00 AM 8/18/2006	
Duct S1	▤	☑	12:00:00 AM 8/19/2006	12:00:00 AM 8/20/2006	
Duct S2	▤	☑	12:00:00 AM 8/21/2006	12:00:00 AM 8/22/2006	
Duct S3	▤	☑	12:00:00 AM 8/23/2006	12:00:00 AM 8/24/2006	
Duct S11	▤	☑	12:00:00 AM 8/25/2006	12:00:00 AM 8/26/2006	
Duct S4	▤	☑	12:00:00 AM 8/27/2006	12:00:00 AM 8/28/2006	
Duct S5	▤	☑	12:00:00 AM 8/29/2006	12:00:00 AM 8/30/2006	
Duct S6	▤	☑	12:00:00 AM 8/31/2006	12:00:00 AM 9/1/2006	
Duct S7	▤	☑	12:00:00 AM 9/2/2006	12:00:00 AM 9/3/2006	
Duct S8	▤	☑	12:00:00 AM 9/4/2006	12:00:00 AM 9/5/2006	
Duct S9	▤	☑	12:00:00 AM 9/6/2006	12:00:00 AM 9/7/2006	
Duct S10	▤	☑	12:00:00 AM 9/8/2006	12:00:00 AM 9/9/2006	
Low side duct sequence 1	▤	☑	12:00:00 AM 9/10/2006	12:00:00 AM 9/11/2006	
Low side duct sequence 2	▤	☑	12:00:00 AM 9/12/2006	12:00:00 AM 9/13/2006	
Exhaust Duct System	▤	☑	12:00:00 AM 9/14/2006	12:00:00 AM 9/15/2006	
1NE Priority Walls	▤	☑	12:00:00 AM 9/16/2006	12:00:00 AM 9/17/2006	
Steel	▤	☑	12:00:00 AM 9/18/2006	12:00:00 AM 9/19/2006	
1NE Fire Sprinkler	▤	☑	12:00:00 AM 9/20/2006	12:00:00 AM 9/21/2006	
1NE Fire Sprinkler 2	▤	☑	12:00:00 AM 9/22/2006	12:00:00 AM 9/23/2006	
FSD	▤	☑	12:00:00 AM 9/24/2006	12:00:00 AM 9/25/2006	
VAV	▤	☑	12:00:00 AM 9/26/2006	12:00:00 AM 9/27/2006	

FIG. 16: The tasks created for each Selection Set for one of the quadrants on the Camino Project.

4.2.5 Step 5: Link 3D Objects and Activities

On the Sequus Project, the General Contractor refined the master schedule to the level of detail required to represent the day-to-day operations of the various subcontractors. This was accomplished by adding and adjusting activities to incorporate the work flow established in step 1 (e.g., activities for piping in zones 1-6) and the installation sequence established by the trades in step 2 (e.g., large pipe will go in before small pipe), as shown in Fig. 13. Consequently, the resulting schedule showed when each of the subcontractors would be working in each zone on the equipment platform. The original schedule contained ten activities for the MEP work and equipment installation on the equipment platform while the refined schedule contained approximately 55 activities for this scope of work.

On the Camino Project, the GC created a separate schedule in the 4D modeling application to represent this scope of work. This was accomplished by creating a task for each Selection Set that was created in step 3. The list of tasks is shown in Fig. 16. These tasks will then be linked to the 3D Selection Sets created in the previous step.

In this step, 3D models are imported into the 4D modeling application and 3D objects are linked with the scheduling activities. The linking process can be automated but it depends on the 4D modeling application used and the degree of coordination with the design.

To create the 4D model on the Sequus project, the team used Bentley's Schedule Simulator. This software imports CAD models and schedule models and transforms them into object-oriented models. We imported each of the CAD models as separate files so that we could easily focus on specific systems. Consequently, eight CAD files were imported into the Schedule Simulator (five process piping models, one HVAC model, one architectural model, and one structural model of the equipment platform). This allowed the project team to view any combination of the different systems in 4D. After the CAD models and schedule model were imported, we manually related the grouped CAD objects created in the third step with the appropriate schedule activity created in the fourth step. For example, one grouped CAD object was the cold water piping system in zone 1 and the corresponding activity was "Install cold water piping in zone 1."

On the Camino Project, Navisworks Timeliner was used to create the 4D model. Links were made between the Selection Sets created in step 3 and the tasks created in step 4. Navisworks provides rules that allow this linking process to be automated based on the name of items, selection sets, or layers, which was utilized on this project. All links between 3D objects and tasks were done automatically based on the name of Selection Sets and tasks, which saved considerable time.

4.2.6 Step 6: Refine 4D Model

The final step involves refining the appearance of the 4D simulation. Most 4D applications allow the user to control the appearance of the objects in the 4D simulation in terms of colors, transparency, timing, filtering, speed, labelling, orientation, etc. Typically, it is useful to create multiple simulations to show all the different perspectives (e.g., interior work and exterior work) and to communicate to different stakeholders (e.g., owners and subcontractors).

On the Sequus Project, the 4D simulation was used to facilitate communication between the general contractor and the owner and between the general contractor and the subcontractors. The 4D model of the work on the equipment platform demonstrated to the owner that the equipment could be installed as planned and wouldn't result in any rework for the MEP subcontractors. For the subcontractors, the 4D model helped identify access issues for equipment installation and identified what areas needed to remain clear to ensure that equipment could be installed as planned. Different 4D simulations were created to show these different perspectives. In terms of appearance, the 4D simulation showed work not yet started as wire-frame, work in progress was highlighted in green for non-critical and red for critical activities, and work completed was shown in the objects' original color (Fig. 13).

On the Camino Project, task types were utilized to change the appearance of the 4D simulation. The task type controls the way the linked Selection Set will be represented visually during the 4D simulation. For example, a task type 'Construction' represents something being built and is shown as green when under construction and then assumes the model color after completion. On the other hand, the task type 'Demolition' starts off with an object being highlighted as Green while the activity is under construction and then disappears after it is completed. Fig. 17 shows four snapshots of the 4D model during the simulation (clockwise from left to right): (1) the full height walls are being framed, (2) the medium pressure ductwork is under construction, and the full height walls as well as the hangers (represented by the little dots) for all the ducts are complete, (3) the low ductwork is under construction and the medium pressure ductwork is complete, (4) the low pressure duct installation is in progress and the medium pressure duct already installed.

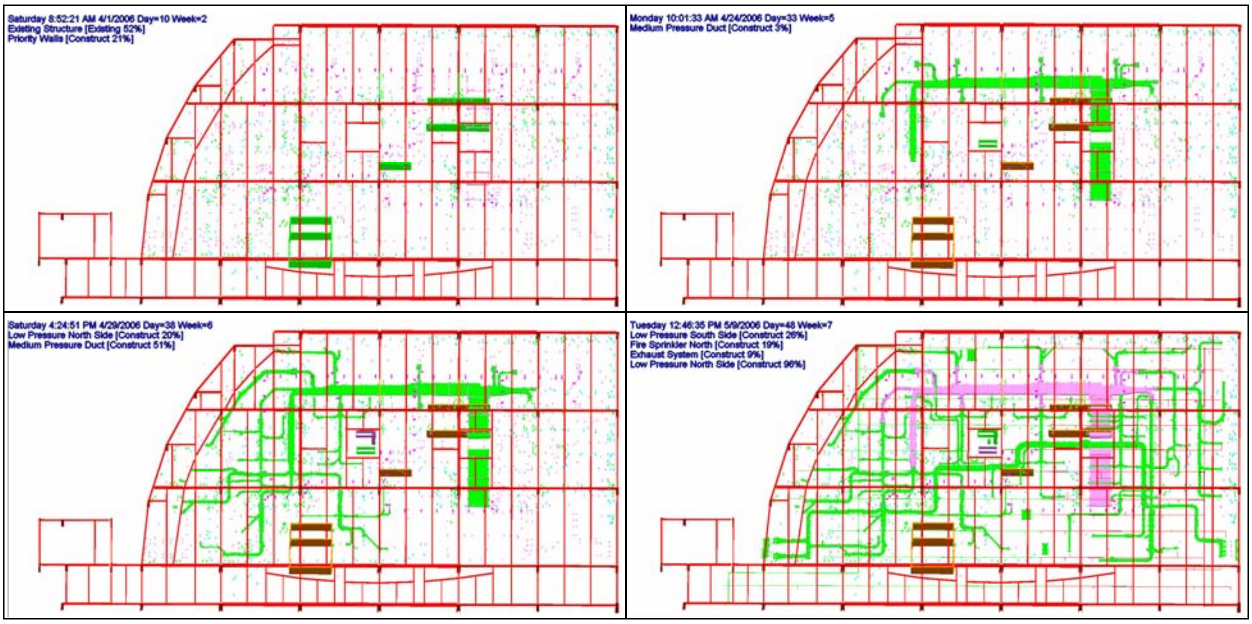


FIG. 17: 4D snapshots of the ductwork and wall framing for the 2nd Floor North East quadrant for the Camino Project. Clockwise from top left the figure shows the installation sequence of the wall framing and ductwork for this quadrant.

4.3 Benefits of 4D Modeling

The following summarizes the benefits of 4D modeling that were realized on the Sequus and Camino Projects:

- **The 4D model assists with coordination of subcontractor schedules**. A 4D model allows all members of the team to visualize their tasks and the relationships that exist between the work of the different sub-trades. On the Sequus project, the 4D model was particularly useful in coordinating the placement of equipment on the platform that was to be installed a month after the ductwork, piping, and conduit work had already started. On the Camino project, the 4D model was useful in coordinating the priority wall framing and the installation sequence of all the duct work.
- **The 4D model clearly communicates schedule intent**. 4D models provide a useful way to communicate the schedule to the different project stakeholders. On the Sequus Project, the 4D model of the equipment platform communicated the schedule intent to both the owner and the MEP subcontractors. The 4D model demonstrated to the owner that the equipment could be installed as planned and to the MEP subcontractors where and when they could work on the equipment platform. On the Camino project, the 4D model allowed the team to better understand the interdependencies between activities and their spatial relationship to laydown areas, which is hard to visualize on the CPM schedule.
- **The 4D model communicates work flow over time.** 4D models provide a superior way of communicating work flow over time compared with conventional bar-chart schedules. On the Sequus Project, the scheduling strategy was to divide the equipment platform into zones to determine the optimal installation path for the air handlers and work sequences between trades, which was communicated graphically in the 4D model. On the Camino project, the big concern was that the subcontractors would interfere with each other if the installation did not proceed in the right order, thus leading to rework and lost productivity. The 4D model helped the subs understand what the optimal sequence should be to optimize productivity for their crews. For example, the drywall and HVAC subcontractors were able to determine the specific walls that should be framed first so that the drywall crew did not have to work around the duct to install their drywall.
- **4D models help identify constructability issues and sequencing problems prior to construction.** Constructability analysis is typically performed during pre-construction by reviewing 2D drawings. However, there are many constructability issues that depend on *when* components are installed. On the Sequus project, the 4D model helped identify access issues for equipment installation and identified what areas needed to remain clear to ensure that equipment

could be installed as planned.

- **4D models show the status of construction at any time in the project.** On the Sequus Project, it was particularly useful to visualize the status of construction when coordinating equipment and material deliveries, determining the path for equipment installation, and communicating to the various parties (especially the owner) how the facility would look at different phases during construction.

4.4 Lessons Learned

The following highlights some observations and lessons learned that would be useful to consider prior to developing 4D models on future projects:

- It is important to determine the purpose of the 4D model as it dictates the level of detail required by the 3D model and the schedule. This should be considered in step 1 of the design coordination process, as mentioned previously.
- Try to set up the 3D model to facilitate 4D modeling whenever possible, particularly in terms of how objects are layered and modeled. This will help to minimize the effort required to reorganize the CAD models to represent the construction perspective (step 3).
- The shelf life of the 4D information is limited. On the Camino Project, we realized that activities for MEP installation in the 4D model are only useful if it is continuously kept up-to-date. The time during which this information is useful for the crew is when this work is in progress and most of the activities happen in one or two days. We were updating the model once a week and it was a challenge to keep up. We think that it would be necessary to keep the model up to date every day to represent the as-built condition and to represent the activities coming up during the week.
- The link between the CAD objects and the schedule activities is not intelligent so be careful if the linking is done manually. For example, we could have linked the "install piping" activity with the graphical object for the door and the system would not detect an inconsistency. It is possible to set up automated linking by giving the CAD objects the same name as the schedule activity but the spelling must be exact and this requires a coordinated effort.
- The 4D modeling system did not help the project team to automatically evaluate the feasibility of the proposed schedule or identify potential conflicts or problem areas. For example, many activities may be occurring at the same time and place resulting in congestion problems and decreased productivity, the path required to install a piece of equipment may be blocked by the execution of a concurrent activity, or the zones implemented to coordinate work flow may not adequately reflect the spatial needs of the various trades. Problems such as these must be identified manually using current 4D tools.

In summary, 4D models can help project teams to coordinate construction disciplines, to communicate construction schedules more effectively, and to assist in the identification of constructability issues early in design development. The limitations pertain to the effort required to set up the CAD and schedule models, the ability of 4D tools to deal with design and schedule changes, and the lack of automated analysis of 4D models.

5. IMPACT OF THE 3D/4D PROCESS ON PROJECT PERFORMANCE

This section describes the overall impact of the 3D and 4D process on the performance of each project.

5.1 Camino Project

On the Camino project, the use of 3D / 4D tools for MEP/FP coordination resulted in significant benefits for the project team:

- Superintendents were able to spend more time on planning the job rather than react to field conflict issues on the project. On Camino project, the Superintendents have spent less than five hours over a three month period dealing with field issues. On comparable projects they typically estimate that they would need to spend 2-3 hours a day dealing with issues related to field conflicts.
- Subcontractors are more knowledgeable about the project as they have been involved sooner and are resolving issues in the design stage that would typically come up in the field. We think that a lot of reciprocal work that happens during construction is now happening during design on the

Camino project, resulting in more efficient planning.

- Only 2 out of 233 RFI's are related to field conflict related issues. We have not yet compared this to other similar projects but believe that by any means this is a phenomenal statistic compared to a traditional project delivery.
- There are ZERO change orders related to field conflicts after the construction of MEP for the project has been completed. This is phenomenal performance compared to similar projects in the industry.
- All the trades finished their MEP rough-in work ahead of schedule. All the MEP work is now complete and the facility is open for business. To date we have done an estimate of productivity improvements through the use of 3D/4D tools for the Mechanical work. The Mechanical trade estimates that their productivity has improved somewhere between 5% to 30% for the construction of piping and sheet metal for the project. This is represented graphically in Fig. 12.
- On the Camino project, after a total of 203,448 man-hours, there was only one recordable injury. The incident rate is 0.98 which is much better than the industry average. The superintendent attributes this to the fact that the workflow has been improved due to the use of 3D/4D models on the project.
- All of the plumbing and medium and low pressure ductwork was pre-fabricated. The subcontractors attribute this to the use of 3D models for coordination. On comparable projects, none of the plumbing and 50% of the ductwork would be the most that the subcontractors would typically pre-fabricate.
- The time spent on pre-fabrication was a lot less compared to doing the same work in the field. For example, the Mechanical Contractor spent 33% less time on fabrication by shifting it to the shop.
- Lower quality labor was utilized in the field compared to other similar projects which typically require higher quality field labor. We think this is largely due to the level of accuracy of the 3D model and because there are fewer mistakes and errors that often result from interpreting 2D drawings.

5.2 Sequus Project

On the Sequus Project, the following benefits were realized:

- Most design conflicts were identified prior to construction resulting in a more productive installation process. There was only one documented design conflict encountered in the field between the MEP subcontractors that modeled their scope of work in 3D.
- Significantly less rework than expected for a project of this complexity. The MEP design coordination process eliminated most of the design conflicts prior to construction. Typically, many conflicts go undetected until they are encountered during installation, often resulting in expensive rework. On the Sequus Project, the only rework that was required occurred between trades that did not model their scope of work in 3D.
- Substantially fewer change orders than expected for a project of this complexity. Rework is often a big cause for the many change orders that typically originate during construction. The project manager for HDCC expected change orders to range from 2-10% of total construction costs, with 2% considered an indicator of a successful project. On the Sequus Project, the percentage of total cost for the MEP work that resulted from change orders was less than 1% (i.e., less than 1% cost growth). However, none of the change orders on this project resulted from unexpected design conflicts for the MEP work.
- All MEP subcontractors reported increases in field productivity. The mechanical subcontractor in particular achieved significant productivity gains. They would dimension the 3D CAD model for the specific pipe components that would be installed for each day and print them out for the field crews. As stated by the project manager: "Field productivity was improved. Even on a system where we did not attempt to do any prefab, the installers were able to refer to small area isometric drawings to facilitate installation."
- 60% fewer Requests for Information (RFI) than expected for a project of this complexity. This is largely due to the fact that the subcontractors were responsible for the detailed design in 3D, and due to the early identification of design conflicts through 3D design coordination.
- Most piping systems were fabricated directly from the 3D model, resulting in time and cost savings and fewer errors. This was particularly useful for the extremely expensive piping that is

used in Sequus' manufacturing processes.

- Improved communication of the schedule intent. The 4D model of the equipment platform communicated the schedule intent to the owner and the MEP subcontractors. The 4D model of the work on the equipment platform demonstrated to the owner that the equipment could be installed as planned and wouldn't result in any rework for the MEP subcontractors. The 4D model showed the MEP subcontractors where and when they could and could not work on the equipment platform.
- Construction was completed on time and under budget.

It is important to note though that these benefits were not realized without compromise. While productivity was improved, design time increased; while rework was avoided, design coordination time increased; while the project team could make more informed decisions, the time it took to actually design, plan, and estimate the facility increased. The increased efficiency of the installation process, however, made up for the increased design cost and time.

6. SUMMARY AND CONCLUSIONS

This paper provides guidelines to help project teams implement 3D and 4D modeling on building construction projects. We believe these guidelines will help project teams overcome the technical, procedural, and organizational challenges that are often a barrier to adopting these technologies. Specifically, the paper describes different approaches for assembling a project team to leverage these technologies, the modeling requirements for implementing 3D and 4D projects, the 3D and 4D modeling processes, the benefits and shortcomings of the process and technologies, the effect of these technologies on the project's outcome, and the lessons learned.

We have found that 3D and 4D modeling can have a significant impact on the execution of a project. The benefits of 3D and 4D modeling are well documented and include: increased productivity, elimination of field interferences, increased pre-fabrication, less rework, fewer requests for information, fewer change orders, less cost growth, and a decrease in time from start of construction to facility turnover. We also believe that the use of these tools will help project teams minimize risk and attract quality team members to construction projects, which will be critical in the coming years as the industry copes with the realities of a tight labor market.

To capitalize on the benefits offered by 3D and 4D technologies, owners, designers, and builders of facilities will need to develop new skills and implement organizational changes. Owners will need to bring a project team together early in the project. Designers will need to focus more on the overall design and coordination of design tasks and less on detailed design. General contractors will need to learn how to manipulate 3D CAD models, work more closely with the designers during design development, and provide input on how to model designs in 3D so that the CAD models are more usable by constructors. Subcontractors will also need to learn design software, as they will be performing more detailed design, working more closely with the architects and engineers through the design process, and addressing coordination issues early in design development.

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